STUDY THE FACTORS AFFECTING ON THE QUALITY OF SKIM COAT

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Degree of Master of Science

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree

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Abstract

Quality of skim coat was examined by using both qualitative and quantitative methodologies. The industrial problems of skim coats are of two major types; mixing related and application related. Analytic Hierarchy Process (AHP) was used to rank these problems according to their relative importance. Difficult to trim, poor workability and poor mixing were having the highest ranking based on the comments given by the manufacturers, retailers and users. The effect of thickener percentage in the skim coat was found to be significant for difficulties in mixing. Mixing was easy up to 0.5% of thickener and the flowability was found to be the best in the range of 0.3–0.6% of thickener. Increase of thickener percentage has increased the tendency for forming agglomerates and lumps of paste during mixing. Good workability and optimum setting could be achieved with 0.3–0.5% of thickener. Optimum performance for trimming could be achieved with 0.3–0.6% of thickener. The above qualitative results were verified quantitatively with the physical testing; ram extrusion, set to touch drying time test, pencil hardness test and dust weight on trimming. According to both qualitative and quantitative analysis, the optimum amount of thickener in skim coat was found to be in the range of 0.3–0.5%.

Keywords – Skim coat, Ram extrusion, AHP, Thickener, Quality analysis

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List of abbreviations

AHP	Analytic Hierarchy Process
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
CE	Cellulose Ether
CL	Carbide Lime
EHEC	Ethyl Hydroxyethyl Cellulose
FTIR	Fourier Transformation InfraRed
HEC	Hydroxyethyl Cellulose
HEMC	Hydroxy Ethyl Methyl Cellulose
HL	Hydrated Lime
HPC	Hydroxypropyl Cellulose
HPMC	Hydroxy Propyl Methyl Cellulose
IS	Indian Standard
MC	Methyl Cellulose
NMR	Nuclear Magnetic Resonance
PMMA	Poly Methyl Meth Acrylate
PSD	Particle Size Distribution
SBR	Styrene Butadiene Rubber

1. INTRODUCTION

1.1 Skim coating

Pre coating is an essential application in building industry. It is applied on rough walls after cementation as the primary coat. Pre coating is mainly used to provide smoothness and base for the paint application. Further it gives a good surface finish. Use of pre coating reduces the paint consumption. There are two types of pre coating materials available in the market. Those are readymade pre-coat in paste form and skim coat in powder form. Readymade pre-coat is the preferable option for the Plasterers as it can be easily applied but it is expensive. On the other hand, skim coats are cheaper but Plasterers find it difficult to apply as compared to pre-coats due to various reasons. Unlike readymade pre-coat, once prepared as a paste, skim coats must be applied before getting dried. Particle size distribution and water content in the paste can seriously affect the quality variation of skim coat. Skim coats are available in market in two forms as Lime based skim coat and Dolomite or Cement based skim coat. Lime based skim coat has no specific formulation. It consists of lime, oil and small amount of other ingredients. Dolomite based skim coat has a specific formulation which contains dolomite, cement, polymer and thickener as the basic ingredients. It is more popular in the market nowadays than lime based skim coat. Hence dolomite based skim coat was selected for the analysis in the present study.

1.2 Problem Identification

According to the comments of skim coat manufacturers and Plasterers, the main problems can be divided into two types as problems on preparation and problems on application. The problems on preparation are mainly associated with difficulty in preparing the paste by mixing the dry powder with water. The main problems on application are working difficulty, quick setting and trimming difficulty. Generally water content to be mixed with skim coat is 35 – 40 % of total weight of skim coat. The prepared mixture should be compatible with wall and it should be easily movable with the aid of a trowel. If these factors can be achieved, the mixture has a good workability. Generally a prepared mixture should be usable for about 2 hours or more. The working time depends on the wall area to be coated and the initial amount of skim coat ready to apply after mixing with water. Usually Plasterers mix about 10 kg at a time. They prefer to have longer working time since they can mix large batch sizes. Most of the products found in industry settle within 2-3 hours. Once settled the product is unusable. Settling is the loosing of workability by means of evaporating water and consequently the mixture solidifies. The required skim coat thickness is about 3 mm. Plasterers by their experience; apply two coats (two times) to attain the required thickness. The settling behavior of mixture critically affects this double layer process. After applying both layers, at least 6 hours is given for drying before trimming (sandpapering). Trimming is the removal of the excess matter to smoothen the surface. According to plasterers, they face several difficulties with this activity. If the dried surface becomes too hard, trimming may result in uneven rough surface. On the other hand, if the dried surface is too soft, too much of the coated surface is removed as dust.

Industrial Technology Institute of Sri Lanka conducts two tests to measure the product quality namely putrefaction and cracking. Putrefaction is used to forecast the product life time or durability. Cracking measures the ability of the coating to withstand without a failure. Both of these tests are related to durability of skim coat after application. However currently construction industry faces problems mostly associated with application difficulties during usage. Therefore present study is mainly focused on identifying the scientific measurements that are suitable for quantifying the quality parameters related with difficulty in application. The suggested list of scientific measurements for analyzing the quality of skim coat in paste form is given in Table 1.1.

Good mixing of powders in dry state is essential before adding water. Ease of mixing is the ability to prepare a workable paste without much difficulty. Uneven mixing may result in non-uniform paste. Formation of agglomerates and lumps cause difficulty in mixing. If the bubbles are trapped during mixing, they may appear on the surface after application. If the water absorption by the mixture is high, more water is needed to prepare a workable paste. However this will eventually affect the consistent quality of the paste during application.

A workable mixture provides the ease to the user who is applying skim coat on the surface with the aid of a trowel. Good workability is the ability to apply skim coat freely on the surface with good compatibility of paste and the surface. After applying such a mixture, dust should not be remained on the paste.

Longer setting time allows more flexibility to the user. But on the other hand, such a mixture takes a long time to dry after application. Then it may become difficult in applying the second layer and the subsequent trimming operation. Plasterers have to wait for a long time to apply the second coat as well as to trim. If the setting time is shorter, paste becomes dry and small quantities have to be prepared but it provides ease of applying the second coat. Therefore optimum setting time is preferred according to the method of application.

In trimming, user should not feel too hard or too soft. If the trimming is easier, more matter is removed with dust. If the trimming is too difficult, it may remove a certain portion of the coating on application of high forces. After trimming the surface should be free of sand paper marks.

1.3 Objectives

The scope of the present study is to develop suitable testing methods to quantitatively analyze the quality of skim coat. Several qualitative parameters are currently practiced in the industry. These qualitative parameters are mostly affected by the amount of retained water in the paste. Retention of water is mainly affected by the formulation and specifically the amount of thickener. Therefore the specific objectives of the project are

1. Rank the qualitative parameters available for analyzing the quality of skim coat according to their relative importance
2. Identify and evaluate the suitability of scientific testing for analyzing the quality of skim coat paste
3. Examine the effect of thickener percentage in skim coat formula using both qualitative and quantitative methods

Table 1.1–Suggested list of scientific measurements for analyzing the skim coat paste

Problem		**Consequences**	**Related Scientific Parameters**	**Available test methods**
Working difficulty		Difficult to apply, Uneven coating	Flowability, Viscosity	Flow table test, Ram extrusion force measurements
Setting difficulty	Fast Setting	Paste becomes dry quickly and hence difficult to apply	Setting time (Drying time)	Vicat needle depth variation with time, Set to touch drying time, Ram extrusion force measurements with time
	Slow setting	Delay in drying and hence delay in trimming and application of second coat		
Trimming difficulty	Too Hard Surface	Have to apply excessive force to trim, Excess trimming, Unexpected scratches	Dry layer hardness	Pencil hardness, Dust weight after sanding Set to touch drying time
	Too Soft Surface	High amount of dust during trimming		

2. LITERATURE REVIEW

This chapter contains an overview of product range in the market, main ingredients of skim coat, compounds similar to skim coat, testing for paste materials and Analytic Hierarchy Process which is the methodology used for quantifying the qualitative problems. In addition to those, a brief introduction was given for ANOVA test which is useful in analyzing the statistical significance of test results.

2.1 Product range in market

A market analysis was conducted to see the product range in Western province in Sri Lanka. Several paint show rooms and hardware were visited and the data were collected. The findings are listed in Table 2.1.

Table 2.1 – Findings of the market analysis

Trade Name	About the product	Volume/Weight per Item	Price/Item (LKR)
Berlux Wall Putty	Readymade	4L	990
Maxbond	Powder form	20kg	750
Dhanushka	Powder form	20kg	650
CIC Skim Coat	Readymade	28kg	1550
DPC Skim Plaster	Powder form	20kg	750
Alpha Skim Coat	Powder form	25kg	850
Madhushika	Powder form	25kg	800

2.2 Main Ingredients of Skim Coat

2.2.1 Dolomite

Dolomite is an anhydrous carbonate mineral composed of calcium magnesium carbonate $CaCO_3.MgCO_3$. Figure 2.1 shows the external appearance of dolomite. The word dolomite is also used to describe the sedimentary carbonate rock, which is composed predominantly of the mineral dolomite [1]. The mineral dolomite was first described by Carl Linnaeus in 1768 [2] [1].

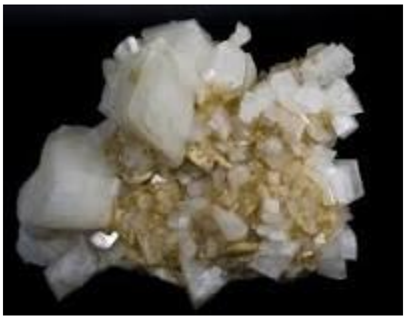

Figure 2.1 - Physical appearance of dolomite

Dolomite is both a mineral and a rock. The mineral is the pure form, and Dolomite rock is composed mostly of Dolomite but also with impurities such as Calcite, Quartz, and Feldspar.

This belongs to hexagonal crystal system. It is available in multi colours as Colorless, white, gray, peach, pink, yellow, and orange, rarely yellow, green, red, and black.

Water solubility of Dolamite is very low or negligible (0.032 g/litre of water at 17^{0}C). Possible products to be formed if dolomite reacts with water are also precipitates of Ca $(OH)_2$ and Mg $(OH)_2$. When dolomite mixes with water, just a physical wetting happens [3].

Dolomite has a number of applications, the most important one is in construction industry, and it may use as a substitute for limestone. However, for some applications dolomite is specifically valued due to its magnesia (MgO) content and chemical composition. Industrial dolomite is a commercial term for dolomite used for non-construction purposes where its chemical properties (or degree of whiteness) are significant [4]. Non construction purposes are the applications excluding the building industry. The examples are plasters used for handicrafts, manufacturing machine parts, ceramic molds and dies etc.

2.2.2 White Cement

Universal blended white cement is a high performance cement that contains a patented formula of naturally and highly reactive pozzolans which are found in geologic deposits. It fastly reacts with water and form Cacium hydroxide since the major constituent of white cement is calcium carbonate. Formed calcium hydroxide reacts with the other minor constituent in white cement and form a dense matrix which cause to provide the strength to skim coat [3]. In white cement amount of transition elements such as Mn and Fe which give the ash colour of cement is very low [5].

In applications, white cement shows two main reactions with water.

1. Formation of $Ca(OH)_2$ which are porous, unstable and easily susceptible to aggressive water and chemical attack. Calcium hydroxide amounts 25% of the cement by volume.
2. Unique blend of pozzolans in universal white cement react with calcium hydroxide and turns into a fibrous cluster like network forming a dense cement matrix. Therefore water tightness or amount of water possible to flow through cement will be reduced. This prevents the entering of chemicals through the matrix which may deteriorate the cement

Greenish brown colour of OPC (Ordinary Portland Cement) derives from a number of transition elements in its chemical composition. The colouring effect will be reduced according to descending order of following d block elements [6].

Cr Mn Fe Co V Ni Ti

White cement has low contents of those ingredients ($Cr_2O_3 \leq 0.003\%$, $Mn_2O_3 \leq 0.03\%$, $Fe_2O_3 \leq 0.35\%$), Generally Mn and Fe occur together in nature. Therefore if Mn is low in a cement, it is in light colour or more closer to white.

2.2.3 Thickener for skim coat

Hydroxyethyl cellulose (HEC) is the most commonly used thickener for skim coat in industry. It is a long chain organic polymer molecule as shown in Figure 2.2. This is non-ionic and water soluble as a result of the polar H in OH groups which are willing to make hydrogen bonds with polar O in water molecules.

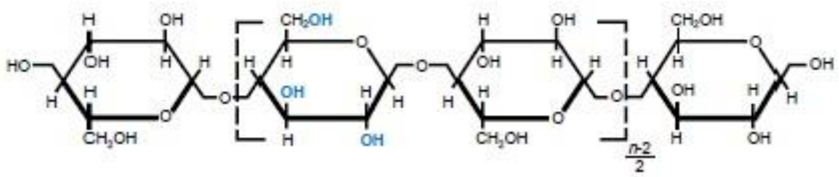

Figure 2.2- Chemical Architecture of HEC

2.2.3.1 Cellulosic associative thickeners

Cellulosic associative thickeners behave as hydrophilic parts as well as hydrophobic parts. These are used in many applications due to their biodegradability, lack of toxicity and abundant raw materials.

Naturally Cellulose is not soluble in water. It can be rendered water-soluble by introducing hydroxyl groups with hydrophilic substituents. By chemical reactions, water soluble cellulose derivatives like carboxymethyl cellulose (CMC), hydroxyethyl cellulose (HEC), methyl cellulose (MC) and hydroxypropyl cellulose (HPC) are produced. These cellulosic polymers may be further modified by reacting with hydrophobic reagents, surfactant macromonomers or water-soluble surface-active monomers, resulting in cellulosic associative thickeners. In addition to that, cellulosic associative thickeners can be prepared by direct reaction of cellulose with the reactive amphiphilic reagents [7].

2.2.3.2 Water solubility of cellulosic associative thickeners

Solubility of thickeners are basically affected by chemical architecture and composition, especially by the hydrophobe content and type. The higher the hydrophobe content and the longer the hydrophobic chain will result in less solubility of thickener in water due to increase of aggregation. When the salinity is increased, the hydrophobe chains are forced into closer and do break down of balance between hydrophobic associative forces and hydrophilic hydration forces. And as a result of that, solubility is decreased. Increasing the concentration of cellulosic associative thickeners causes the system to pass from dilute to semidilute gel phase [7].

2.2.3.3 Viscosity of solutions containing cellulosic associative thickeners

The viscosity property of thickeners in aqueous solution is strongly influenced by the intra and intermolecular aggregation. The aggregation level depends largely on the content and structure of the bound hydrophobe.

Pseudoplastic behavior has been observed in cellulosic thickeners. Hydrophobic interactions are disrupted with shear rate. Then viscosity of solution is decreased. But when the shear is removed, the hydrophobic interactions are rearranged and viscosity is recovered. According to that, formation of hydrophobic aggregates is reversible.

Adding NaCl into media develops the viscosity of cellulosic thickeners due to enhancing the formation of interchain hydrophobic aggregation. On the other hand addition of organic solvents causes a decrease in the viscosity. The reason may be due to hydrophobic interaction break down with organic solvents [7].

2.2.3.4 Surface activity of cellulosic associative thickener

The amphiphilic nature of cellulosic associative thickeners is expected to induce a decrease in water surface tension and oil/water interfacial tension. By introducing different additives into media, surface tension can be lowered. The surface and interfacial tensions depend on the polymer concentration, the species and content of the hydrophobe, chemical architecture and other factors such as temperature and time [7].

2.2.3.5 Adsorption behavior

Due to hydrophobic groups, cellulosic associative thickeners have adsorption ability on many hydrophobic substrates. That effect is useful in potential applications as stabilizers of aqueous dispersions, emulsions and forms [7].

2.2.3.6 Gel formation

Certain cellulosic associative thickeners have the ability to form stiff, water-swollen hydrogels under suitable conditions. Hydrophobically modified HEC is one example [7].

2.2.4 Polymers used in skim coat

Water-soluble polymers are used to improve the application properties of paste type products. They do the stabilization of paste and improving the properties like workability, rheology, water retention and adhesion properties [8]. Skim coats and precoats are commonly used as plastering materials which are very similar to joint compound in applications and physical properties. Compounds similar to skim coats are discussed in section 2.3.

Some of the industrial polymer products for plasters are

- Nexton water-soluble polymers
- Culminal methylcellulose derivatives
- Natrosol hydroxyethylcellulose
- Aqualon carboxymethylcellulose
- Galactasol guar derivatives

2.2.4.1 The effect of polymers on water retention of pastes

Controlling and managing the large volume of water present in paste is an important function. This includes thickening and control of product rheological properties, as well as the prevention of syneresis in storage, water evaporation and absorption into the substrate during application. Compound workability, open time and adhesion are maximized by optimizing water retention. Effective control of the water activity extends paste stability by controlling time thickening and syneresis [8].

2.2.4.2 The effect of polymers on workability of pastes

The pseudoplastic or shear-thinning rheology is provided by water-soluble polymers. They offer superior application properties as the paste is troweled onto the board surface. The compound is soft and easy to remove from the container; high quality compound spreads easily to cover the wallboard uniformly by creating a smooth surface which is easily sanded upon drying. The superior water holding ability of the water-soluble polymer allows for long open time during application and extends the time before the joint compound becomes thick and unmanageable due to excessive loss of water [8].

2.2.4.3 The effect of polymers on Adhesion of pastes

Adhesion is a function of the control of water activity and limited interaction between the water-soluble polymer and minerals present in the paste. Polymer products play a vital role in hundreds of different product formulations. Application areas include personal care, pharmaceuticals, paper, cement and gypsum-based products, food, paints and coatings, emulsion polymers, and latex-based building materials [8].

2.2.4.4 The effect of polymers on stability of pastes

The chemical stability of water-soluble polymers in the diverse chemical environment offers excellent long-term stability based upon aging. Polymer compatibility with all ingredients and ease of homogeneous dispersion during compound manufacturing results equilibrium at pack out, so that further dissolution with subsequent undesirable rheology changes will not happen [8].

2.2.4.5 The effect of polymers on dry properties of pastes

Pastes made with water-soluble polymers as they dry to a homogeneous, smooth, and easy-to-sand in finishing. The integrity imparted by the polymer prevents the dried coating from flaking or coming off the wall. A humid environment will not cause absorption of moisture which could lead to swelling and loss of bond between the paper tape and the wallboard [8].

2.3 Compounds similar to skim coat

Mortars, plasters and joint compounds are some examples for materials similar to skim coat. All these materials are in dry powder form and those should be mixed with water in application. In mixing and prior to apply, the physical appearance of above material is like a paste. That is how these materials become similar to skim coat. Mortar consists of pitch, asphalt, and soft mud or clay that is used in building construction to bind bricks together [9]. Plaster is a building material derived from gypsum, lime or cement which is used for coating walls and ceilings [10]. Joint compound is a white substance similar to plaster used with joint tape to seal joints between sheets of drywall, primarily in building construction. Other terms are drywall compound or mud. It is often referred to simply as mud or as joint cement [11]. The materials are also similar to plaster constituents.

2.3.1 Mortar and Lime as building materials

Mortar is a workable paste used to bind building blocks like stones, bricks, and concrete Plastererry units together. They fill and seal the irregular gaps between those units and sometimes bring decorative colors or patterns in Plastererry walls. Mortar comes from a Latin word mortarium which has the meaning of crushed.

Cement mortar will hard when it cures, resulting in a stiff aggregate structure. It is intended to be weaker than the building blocks since mortar is easier and less expensive to repair than the building blocks. Mortars are prepared by a mixture of sand, a binder, and water. If the binder is lime in composition, it is called as lime mortar. Lime and gypsum in the form of plaster of Paris are used particularly in the repair and allied activities of buildings and structures with the purposing of attaining repair materials similar to the original materials: The type and ratio of the repair mortar is determined by a mortar analysis. There are several types of cement mortars and additives [9].

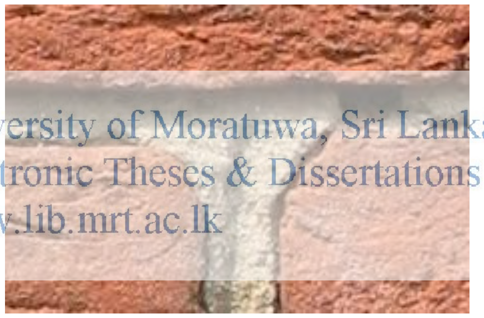

Figure 2.3-Mortar used to bind bricks together

In acetylene/ethylene (C_2H_2) production reaction using calcium carbide and water, calcium hydroxide is a byproduct in addition to ethyne. In the reactor mixture, calcium hydroxide is mainly composed with minor parts of carbonate since ethylene is a gas. Calcium hydroxide is derived from lime and water and therefore it is called as hydrated lime (HL). Carbide mixed lime is called as carbide lime (CL). Dry hydrated lime is used as a building material [10].

2.3.1.1 The role of aggregates of lime mortars

Mortar is an application of lime and similar materials which have been used for centuries in Civil Engineering construction. Considering ancient monuments and historical buildings it can be seen that the materials used for mortars are durable although they are of low strength compared to cement mortars. Resistance to weathering is measured by capillary porosity by suction. Coarse aggregates contribute to the volume stability of lime mortars and independent of strength enhancement when adequate compaction reduces the capillary pores. If binder/aggregate ratio is low, porosity is low and strength will be high. In this scenario, the aggregate maximum size is 0-4 mm [11].

2.3.1.2 Water retention and consistency in cement-based mortars

Cellulose ethers (CE) are materials used as additives to improve the quality of cement-based mixtures. They behave as admixtures by improving the properties like water retention, workability and open time. Polysaccharides such as starch derivatives are used to develop the consistency of the fresh materials. The effect of CE and their physio-chemical parameters such as molecular weight and substitution degrees on water retention and rheological properties of mortars are considered as fresh stage properties of cement based mortars [12]. According to rheological measurements, CE behaves as a thickener up to 0.27% in mixture. Water retention capability is dominant than the molecular weight effect [12].

2.3.2 Plaster and Joint Compound

Plaster is a building material derived from gypsum, lime or cement which is used for coating walls and ceilings. It is manufactured as a dry powder and is mixed with water to form a paste when used. The reaction with water liberates heat through crystallization. Afterwards hydrated plaster hardens. Plaster can be easily worked with metal tools or sandpaper. These behaviors make plaster suitable for a finishing, rather than a load-bearing material [13].

Figure 2.4– Application of Joint Compound

2.3.2.1 Water and solvent effects on the strength of set plaster

Set plaster is known as a modeling material for rock mechanics. The mechanical properties varying during drying and wetting of plaster are much important. It loses about 50% of its mechanical strength when it absorbs 2% of water. But when drying, the lost portion can be compensated [13].

2.3.2.2 Latex-filled plaster composites

Addition of latex to plaster, results in a coarser crystallisation, a disturbance of the plaster hydration and a higher porosity. These changes are the more pronounced so as the concentration of latex is high. It is shown that the presence of latex noticeably modifies the porous network of the plaster [14].

Incorporating Latex types into plaster composites, increases the setting time and decreases the flexural and compressive strength. Such Latex additives are polyvinyl acetate, Styrene Butadiene Rubber (SBR) and Poly Methyl Mech Acrylate (PMMA). Water requirement of plaster is decreased with the concentration of Latex. PMMA impregnated plasters have a great improvement in compressive strength [15].

2.4 Testing for paste materials

This section explains the background of test methodologies used in quantitative analysis of skim coat. The following tests are commonly used for similar type of paste materials to evaluate their performance in practical applications. Those were selected as suitable test methods since skim coat has not been evaluated previously by any other test procedures.

2.4.1 Flow table test

This is a standard test method (ASTM C230/C230M-13) to determine the flowability of cements or mortars. The test results denote the applicability of the material after mixing with water. This helps to ensure the consistency also. The flow table shall consist of an integrally cast rigid iron frame and a circular rigid table top with a conical mold as shown in figure 2.5. The conical mold is used for casting the flow specimen and a caliper is used for measuring the diameter of the mortar after it has been spread by the operation of the table [16].

Figure 2.5 – Standard flow table

2.4.2 Vicat needle depth measurement

The Vicat test is a standard test for measuring the setting times of cement paste and mortar. The physical background of the test is based on the resistance of a paste to dynamic penetration by a rod with a certain weight and shape (shear strain). The initial and final setting time information is very useful to compare cement setting properties [17]. This test is used mainly for two purposes; to measure the standard consistency of cement and to measure initial and final setting time.

The standard consistency of a cement paste is defined as that consistency which will permit the vicat plunger to penetrate to a point 5 to 7mm from the bottom of the vicat mold [18] This test method is intended to be used to determine the amount of water required to prepare hydraulic cement pastes for testing [19].

Initial setting time is the time elapsed between the initial contact of cement and water and the time when a 1mm cross-section diameter needle gives a reading less than 25mm from the bottom in a standard Vicat apparatus is known as initial setting time of that particular cement paste. Final setting time is the time elapsed between the initial contact of cement and water and the time when the smaller needle (1mm cross-section diameter) doesnot penetrate or does not leave an impression on the cement paste. [20].With Portland cement and rapid hardening cement, initial setting time shall not be less than 30 minutes and final setting time should be more than 10 hours [21]

The apparatus consists of a standard mold, a calibrated scale and a kit of standard needles. Figure 2.6 and Figure 2.7 show the external appearance of equipment and the dimensions of the unit respectively.

Figure 2.6– Vicat needle apparatus

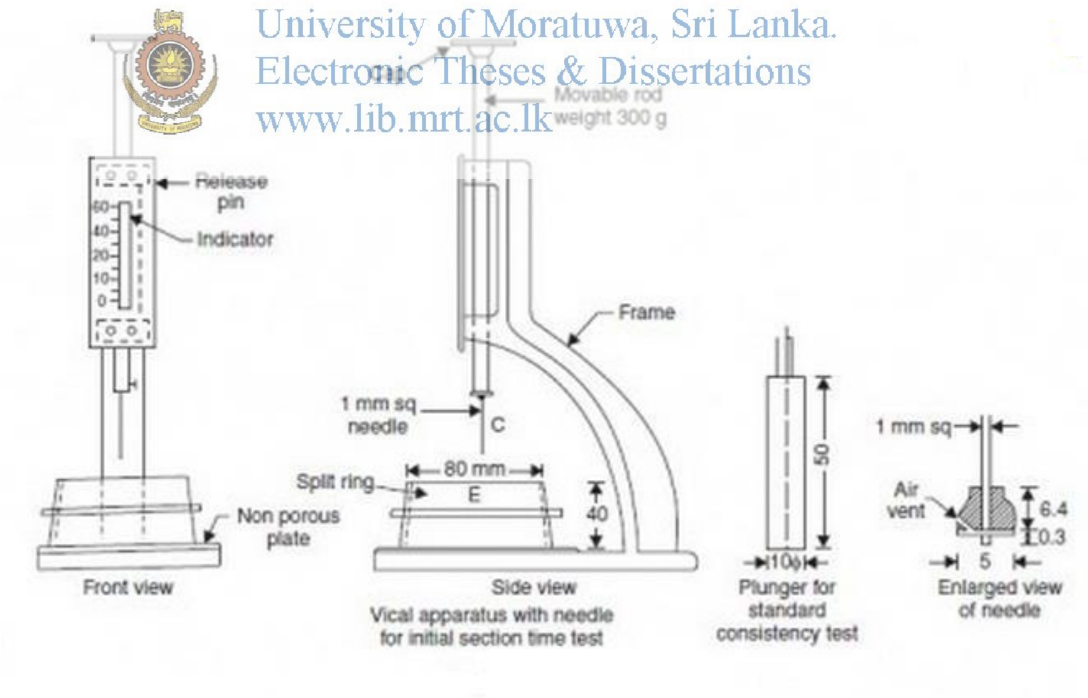

Figure 2.7– Dimensions of Vicat needle apparatus

2.4.3 Ram extrusion

Short fiber-reinforced semi solid fresh pastes and mortars have much lower water to binder ratio and higher viscosity than normal cement pastes or mortars. Normal fresh cement pastes or mortars have much greater water to binder ratio and lower viscosity. The methods suitable to characterize the rheology of low viscous mixtures are not applicable for high viscous mixtures. Orifice extrusion that is commonly known as ram extrusion has been identified as a suitable way to calibrate rheology of the semi-solid fresh cement mortar [22]. A sketch of a ram extruder is given in figure 2.8.

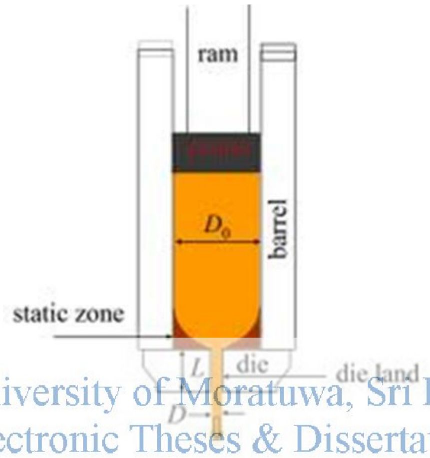

Figure 2.8– Sketch of Ram extruder

In this operation, the paste is allowed to pass through a small orifice located at the bottom of a narrow cylinder. The paste is pushed by a plunger. The force required to push the plunger is measured. Similar measuring method could be used to analyze the workability of skim coat. Standard viscometers cannot be used for measuring the paste viscosity since the viscosity level to be measured is higher than the maximum viscosity that can be measured by a viscometer. Therefore Rotational or Brookfield viscometer is not suitable for this purpose. Use of a cup (Iso cup, Ford cup, Zahn cup etc.) is another option but again it is not viable due to high viscosity and adhesion of paste on the walls of the cup. On the other hand ram extrusion was found to be an ideal option to measure the viscosity of paste materials where the extrusion force required to flow the paste through a tube of constant diameter die land is measured [23]. If the viscosity is high, the force to be applied to compress the sample is high. Then by measuring the extrusion force, workability can be measured.

2.4.4 Pencil Hardness Test (ASTM D3363)

The Pencil Hardness Gauge is used to determine the hardness of an organic coating. The results are recorded as the hardest pencil that does not scratch or mark the surface of the coating (this is the scratch hardness interpretation not the gauge hardness interpretation). The gauge can be used on both liquid painted and powder coated surfaces. The procedure and assessment of the results are the same for both. The gauge is equipped with the leads located in the following standard positions as given in Table 2.2.

Table 2.2 – Order of pencils from lowest to highest hardness

9B	8B	7B	6B	5B	4B	3B	2B	B	HB	F	H	2H	3H	4H	5H	6H	7H	8H	9H

The difference between two adjacent leads is considered as one unit of hardness. Testing is to proceed from the hardest lead to the softest lead [24]. Figure 2.9 shows the external appearance of a pencil hardness tester.

Figure 2.9 – Pencil Hardness Tester

2.5 Analytic Hierarchy Process

This is a methodology which helps to quantify the qualitative measurements when it is very complex and decision making is difficult. Analytic Hierarchy Process (AHP) is a decision analysis approach which has been developed by Thomas L.Satty in 1971[25]. As an easy-use and very practical tool based on a simple theory, AHP is capable to extract the comments of multiple experts and decision makers regarding quality, and is mainly applicable to handle the problems arising in an uncertain environment in which multiple evaluation criteria exist. AHP is used to systemize or to simplify the complicated problems and dissolve these factors into different levels from various directions. A comprehensive analysis is conducted through the process of quantification to assist decision makers in the selection of appropriate plans [26].

There are 3 main steps in AHP analysis [27],

1. State the objective
2. Define the criteria and Pairwise comparison
3. Pick the alternatives

<u>State the objective</u>

In this step, the objective is identified or defined correctly and the next actions should be taken to achieve the targets of that objective.

<u>Define the criteria and Pairwise comparison</u>

As criteria, the factors affecting on the task are listed out and a comparison is done between two of each criterion numerically. This is done with the purpose of comparing the relative importance of each criterion among others. That is known as pairwise comparison. Finally a matrix is obtained as Pairwise comparison matrix. It is a square matrix and the number of rows or columns is equivalent to number of criterion. A second vector is obtained by summing up the row elements. It is a column vector and it is used to derive the eigen vector of criteria. Eigen values are calculated by dividing the elements in second vector by the total of individual elements in second vector.

<u>Pick the alternatives</u>

Final result of AHP is one of alternative options. Pairwise comparison is done among alternatives for each criterion. Comparison matrices are obtained for each criterion. As same as above, eigen vectors are calculated separately for all criteria. A new matrix is prepared by combining the elements of eigen vectors. In this matrix, number of rows is equivalent to number of alternatives. Then this matrix is multiplied by the eigen vector obtained for criteria. Then the final eigen vector is obtained which is having one column and equal number of rows to the alternatives. The alternative number which is having the maximum eigen value is the best selection. It is the final result of the exercise.

AHP has been successfully used in many different types of research works in the past [28-29]. In one of the applications, AHP was used to evaluate bioenergy developments regarding their regional sustainability in a case study area (Tayside and Fife/Scotland). In this study, two different scenarios and their alternatives, C&I (criteria and indicators) and preferences of bioenergy experts were considered as key elements. The detailed analysis of results, including analysis by end node C&I and by alternatives, revealed that decentralized bioenergy generation was favorable to gain regional sustainable bioenergy generation in the case study area. Results of the Sensitivity analysis done on different levels of AHP hierarchies had shown that all results seemed to be robust [29].

2.6 ANOVA test

Analysis of Variance (ANOVA) is a statistical method used to test differences between two or more means [30]. ANOVA was developed by R.A. Fisher. Here, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the t-test to more than two groups. As doing multiple two-sample t-tests would result in an increased chance of committing a statistical type I error, ANOVAs are useful in comparing (testing) three or more means (groups or variables) for statistical significance [31].

Generally in ANOVA test, the significance of test results or a data set is evaluated by p value. If the p value is less than 0.05 the data available are more sensitive and accurate. If the p value is greater than 0.05, the data cannot be accepted.

3. QUALITATIVE ANALYSIS OF THE INDUSTRIAL PROBLEM

3.1 Classification of Industrial Problem

As described in problem identification in section 1.2, quality of skim coat can be analyzed at 3 different stages; preparation, application and durability. Test methods for analyzing the quality in terms of durability are already available. Therefore the quality parameters related with the preparation and application of skim coat were analyzed in this study. Analytic Hierarchy Process (AHP) was used to analyze the comments of skim coat manufacturers and users (Professional plasterers). They commented on problems associated with both preparation stage and application stage and these problems are summarized in Table 3.1. The descriptions given in Table 3.1 were used in developing the pairwise comparison matrices as explained in section 3.3

3.2 Materials and Methodology

Based on Literature and specifications given by the manufacturers of skim coat available in the market, formula was selected. White cement content and polymer content were kept constant as 12% and 0.3% (w/w) respectively. Two types of dolomite are commonly used in Sri Lanka to manufacture skim coats; industrial grade CC450 and industrial grade CC200. The industrial grade CC450 was selected for the present study and a skim coat available in the market having similar particle size distribution (see Appendix A) was also selected for comparison. Problems associated with applications of skim coat as given in Table 3.1, are mainly dependent on retention of water which is a direct function of thickener. Therefore thickener percentage was varied from 0.1%-0.8% and the dolomite percentage was adjusted accordingly to keep the total batch weight constant as given in Table 3.2. Samples of weight 2.5 kg for each formulation were prepared for testing. These samples were given to four experienced Plasterers (as recommended by the manufacturers) and they were asked to apply the sample coating on a rough wall. Then their feedback was recorded for quality factors given in Table 3.1. The feedback given by 4 Plasterers were used as qualitative results for the analysis using Analytic Hierarchy Process (AHP)

Table 3.1 – Description of issues to derive pairwise comparison matrix

Problem	Description	Favourable outcome
1. Poor mixing	Difficult to mix evenly while adding water	Ease of mixing
2. Dust during application	Observation of dust while applying	No dust surface
3. Bubbles after applying on the surface	Observation of air bubbles after application	Low air bubbles
4. Fast setting	Time taken to lose the applicability of mixture should not be too short in order to avoid difficulty in application	Long Setting time
5. Difficult to trim	Ability to cut the excess matter using sand papers and obtaining a smooth surface	Ease of trimming
6. Poor Workability	Ability to apply the mixture on the wall with the aid of a trowel	Good workability
7. Sand paper marks	Observation of sand paper marks on the finished surface	No sand paper marks
8. Agglomeration while mixing	Particle agglomeration behavior while mixing	Low agglomerates
9. Dust on trimming	Fall of dust during trimming	Low trimming dust
10. Poor flowability during mixing	Difficult to maintain good flowability during mixing	Good flowability during mixing
11. Unmixed lumps	Appearing dry particles on wall after application	Low unmixed lumps
12. Stiff paste	Absorption of water by skim coat should not be high in order to avoid stiff paste	Soft and uniform paste

Table 3.2– Formulations of skim coat samples

Formulation number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Dolomite (%)	87.6	87.5	87.4	87.3	87.2	87.1	87.0
Cement (%)	12	12	12	12	12	12	12
Polymer (%)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Thickener (%)	0.1	0.2	0.3	0.4	0.5	0.6	0.7

3.3 Application of Analytic Hierarchy Process

3.3.1 Main Steps of AHP

<u>State the objective</u>

The objective was to optimize the thickener content.

<u>Define the criteria & Pairwise comparison</u>

Criteria were defined as the most favorable outcome of the problem. The expected favorable outcome for each problem is given in Table 3.1. Each and every favorable outcome was compared with all the other favorable outcomes as given in Table 3.3. For an example; “Good workability” is 3 times important than “Low trimming dust” but equally important to “Ease of mixing”. Therefore Table 3.3 is a summary of relative importance of each criterion among others, based on the comments given by skim coat manufacturers and Plasterers.

The data in Table 3.3 was then used to quantify the pairwise comparison in order to rank them according to the relative importance. The relative importance in Table 3.3 was presented in decimals and a matrix of size (12X12) was prepared (M1) as given below.

$$
M1 = \begin{pmatrix}
1.00 & 2.00 & 3.00 & 1.00 & 1.00 & 1.00 & 3.00 & 1.00 & 3.00 & 1.00 & 2.00 & 3.00 \\
0.50 & 1.00 & 1.00 & 0.50 & 0.50 & 0.33 & 1.00 & 0.50 & 1.00 & 0.50 & 1.00 & 0.50 \\
0.33 & 1.00 & 1.00 & 0.33 & 0.25 & 0.33 & 1.00 & 1.00 & 1.00 & 0.33 & 1.00 & 0.50 \\
1.00 & 2.00 & 3.00 & 1.00 & 0.33 & 0.33 & 3.00 & 2.00 & 2.00 & 1.00 & 2.00 & 2.00 \\
1.00 & 2.00 & 4.00 & 3.00 & 1.00 & 1.00 & 4.00 & 4.00 & 3.00 & 2.00 & 2.00 & 3.00 \\
1.00 & 3.00 & 3.00 & 3.00 & 1.00 & 1.00 & 3.00 & 2.00 & 3.00 & 1.00 & 2.00 & 1.00 \\
0.33 & 1.00 & 1.00 & 0.33 & 0.25 & 0.33 & 1.00 & 0.50 & 1.00 & 0.33 & 0.50 & 1.00 \\
1.00 & 2.00 & 1.00 & 0.50 & 0.25 & 0.50 & 2.00 & 1.00 & 1.00 & 0.50 & 1.00 & 1.00 \\
0.33 & 1.00 & 1.00 & 0.50 & 0.33 & 0.33 & 1.00 & 1.00 & 1.00 & 0.50 & 1.00 & 0.50 \\
1.00 & 2.00 & 3.00 & 1.00 & 0.50 & 1.00 & 3.00 & 2.00 & 2.00 & 1.00 & 2.00 & 2.00 \\
0.50 & 1.00 & 1.00 & 0.50 & 0.50 & 0.50 & 2.00 & 1.00 & 1.00 & 0.50 & 1.00 & 0.50 \\
0.33 & 2.00 & 2.00 & 0.50 & 0.33 & 1.00 & 1.00 & 1.00 & 2.00 & 0.50 & 2.00 & 1.00
\end{pmatrix}
$$

Table 3.3– Pairwise comparison among criterion selected to analyze skim coat

	Ease of Mixing	No dust surface	Low air bubbles	Long setting time	Ease of Trimming	Good Workability	No sand paper marks	Low agglomerates	Low trimming dust	Good flowability during mixing	Low unmixed lumps	Soft and uniform paste
Ease of Mixing	1/1	2/1	3/1	1/1	1/1	1/1	3/1	1/1	3/1	1/1	2/1	3/1
No dust surface	1/2	1/1	1/1	1/2	1/2	1/3	1/1	1/2	1/1	1/2	1/1	1/2
Low air bubbles	1/3	1/1	1/1	1/3	1/4	1/3	1/1	1/1	1/1	1/3	1/1	1/2
Long setting time	1/1	2/1	3/1	1/1	1/3	1/3	3/1	2/1	2/1	1/1	2/1	2/1
Ease of Trimming	1/1	2/1	4/1	3/1	1/1	1/1	4/1	4/1	3/1	2/1	2/1	3/1
Good Workability	1/1	3/1	3/1	3/1	1/1	1/1	3/1	2/1	3/1	1/1	2/1	1/1
No sand paper marks	1/3	1/1	1/1	1/3	1/4	1/3	1/1	1/2	1/1	1/3	1/2	1/1
Low agglomerates	1/1	2/1	1/1	1/2	1/4	1/2	2/1	1/1	1/1	1/2	1/1	1/1
Low trimming dust	1/3	1/1	1/1	1/2	1/3	1/3	1/1	1/1	1/1	1/2	1/1	1/2
Good flowability during mixing	1/1	2/1	3/1	1/1	1/2	1/1	3/1	2/1	2/1	1/1	2/1	2/1
Low unmixed lumps	1/2	1/1	1/1	1/2	1/2	1/2	2/1	1/1	1/1	1/2	1/1	1/2
Soft and uniform paste	1/3	2/1	2/1	1/2	1/3	1/1	1/1	1/1	2/1	1/2	2/1	1/1

Then M1 was squared to get M2

$$M2 = \begin{pmatrix} 12.00 & 32.00 & 36.00 & 16.50 & 9.58 & 12.50 & 36.00 & 25.50 & 33.00 & 13.50 & 28.50 & 23.00 \\ 5.00 & 12.00 & 14.00 & 6.67 & 3.88 & 4.58 & 15.00 & 10.17 & 12.50 & 5.50 & 10.67 & 9.33 \\ 4.75 & 11.50 & 12.00 & 5.67 & 3.44 & 4.19 & 13.50 & 8.83 & 11.08 & 4.75 & 9.67 & 7.92 \\ 11.00 & 27.67 & 29.33 & 12.00 & 7.83 & 10.33 & 31.33 & 20.50 & 27.00 & 11.00 & 23.83 & 19.83 \\ 18.67 & 46.00 & 50.00 & 21.67 & 12.00 & 16.33 & 53.00 & 36.00 & 44.00 & 18.67 & 39.00 & 33.50 \\ 14.83 & 35.00 & 40.00 & 18.50 & 10.33 & 12.00 & 43.00 & 29.00 & 35.00 & 15.50 & 30.50 & 26.50 \\ 4.17 & 11.00 & 12.00 & 5.42 & 3.24 & 4.19 & 12.00 & 8.33 & 11.08 & 4.50 & 9.67 & 7.67 \\ 6.92 & 17.00 & 18.50 & 8.25 & 5.33 & 6.42 & 19.50 & 12.00 & 17.25 & 7.00 & 14.50 & 12.75 \\ 5.17 & 12.33 & 13.33 & 6.25 & 3.67 & 4.50 & 14.83 & 9.83 & 12.00 & 5.25 & 10.50 & 8.83 \\ 11.83 & 30.00 & 32.00 & 14.50 & 8.67 & 11.17 & 34.00 & 22.50 & 29.50 & 12.00 & 25.50 & 21.00 \\ 6.00 & 14.50 & 16.00 & 7.75 & 4.42 & 5.33 & 17.50 & 11.50 & 14.50 & 6.25 & 12.00 & 11.00 \\ 7.67 & 19.33 & 20.33 & 10.33 & 6.08 & 7.17 & 22.33 & 15.17 & 19.00 & 8.00 & 16.83 & 12.00 \end{pmatrix}$$

The next step was to prepare a column vector by taking the sum of elements in each row of M2. This vector C1 has 12 rows and one column.

$$C1 = \begin{pmatrix} 278.08 \\ 109.29 \\ 97.31 \\ 231.67 \\ 388.83 \\ 310.17 \\ 93.26 \\ 145.42 \\ 106.50 \\ 252.67 \\ 126.75 \\ 164.25 \end{pmatrix}$$

The elements of column vector were summed up to calculate the row total.

Row total = Σ Row sum (Row elements)

= 2304.19

The eigen vector (e1) was then calculated by dividing each and every row element of C1 by row total. Each eigen value was corresponded to the order of criterion given in Table 3.3.

$$e1 = \begin{pmatrix} 0.1207 \\ 0.0474 \\ 0.0422 \\ 0.1005 \\ 0.1688 \\ 0.1346 \\ 0.0405 \\ 0.0631 \\ 0.0462 \\ 0.1097 \\ 0.0550 \\ 0.0713 \end{pmatrix}$$

The accuracy of the eigen vector e1 was rechecked by re-squaring the M2 and recalculating the second eigen vector by following a similar procedure. The new eigen vector e2 is

$$e2 = \begin{pmatrix} 0.1269 \\ 0.0501 \\ 0.0446 \\ 0.1053 \\ 0.1761 \\ 0.1411 \\ 0.0426 \\ 0.0667 \\ 0.0487 \\ 0.1152 \\ 0.0074 \\ 0.0754 \end{pmatrix}$$

The difference between the corresponding row elements in first (e1) and second (e2) eigen vectors were calculated. If the difference is negligible, the calculation is considered to be correct. If there is a significant difference between first and second eigen vectors, repeat the matrix squaring & recalculating eigen vectors until a negligible difference is obtained between last two eigen vectors [27].

Since the difference of first and second eigen vectors was almost equal to zero, the second eigen vector (e2) was selected as the final eigen vector.

$$\text{Difference between first two eigen vectors} = \begin{pmatrix} 0.0062 \\ 0.0026 \\ 0.0023 \\ 0.0048 \\ 0.0073 \\ 0.0065 \\ 0.0021 \\ 0.0035 \\ 0.0025 \\ 0.0056 \\ -0.0476 \\ 0.0041 \end{pmatrix}$$

Final eigen values for different factors are given in Table 3.4.

Table 3.4– Calculated eigen vectors for criterion selected to analyze skim coat

Criterion	**Eigen Vector**
Ease of Mixing	0.1269
No dust surface	0.0501
Low air bubbles	0.0446
Long setting time	0.1053
Ease of Trimming	0.1761
Good Workability	0.1411
No sand paper marks	0.0426
Low agglomerates	0.0667
Low trimming dust	0.0487
Good flowability during mixing	0.1152
Low unmixed lumps	0.0074
Soft and uniform paste	0.0754

Ranking was given as the order of magnitude of Eigen values. Table 3.5 was arranged to show the importance of criterion based on their ranking.

Table 3.5– Arranging criteria according to priority based on calculated eigen vectors

Rank	**Criterion**	**Eigen Vector**
1	Ease of Trimming	0.1761
2	Good Workability	0.1411
3	Ease of Mixing	0.1269
4	Good flowability during mixing	0.1152
5	Long setting time	0.1053
6	Soft and uniform paste	0.0754
7	Low agglomerates	0.0667
8	No dust surface	0.0501
9	Low trimming dust	0.0487
10	Low air bubbles	0.0446
11	No sand paper marks	0.0426
12	Low unmixed lumps	0.0074

According to the Table 3.5, Ease of trimming has the highest eigen value and hence it gets the highest priority. The second highest priority is given to Good workability. Both of the highest and the second highest priorities are related to the problems associated with application but third and fourth are related to the problems associated with mixing.

The next important step in AHP is to pick the alternatives.

<u>Pick the alternatives</u>

In this exercise, alternatives were selected as the 7 formulations and one commercial product. Each criterion was evaluated with respect to all the formulations as per comments made by experienced Plasterers. The seven formulations are given in Table 3.2. Formulation number 8 was assigned to the skim coat obtained from the market with similar particle size distribution as explained in section 3.2.

Evaluation of different formulations was also done by the same procedure as used in defining the criteria. For a specified criterion (eg: Ease of mixing), pairwise comparison was done among the 8 formulations. Then fractions were converted into decimals and the matrix was created. It was squared and the row elements were summed up. Finally eigen vectors were calculated for each and every criterion.

3.3.2 Evaluation of different formulations

Table 3.6 shows the comparison among formulations about their behavior in mixing based on the comments provided by Plasterer 1. The last column is the calculated eigen values for ease of mixing for 8 different formulations. The maximum eigen value indicates the best formulation for ease of mixing based on the comments made by Plasterer 1. Similarly the rest of formulations can also be ranked according to the eigen values. Appendix B contains similar comparisons for remaining criteria based on the comments of Plasterer 1. Then another matrix (M3) can be prepared by using the eigen vectors obtained for different criteria. In this matrix columns denote criteria and rows denote formulations. The matrix (M3) was then multiplied by the eigen vector of the pairwise comparison among criteria (e2) and the final resultant column vector (e3) was obtained. The maximum eigen value of this column vector is the best formulation by considering overall criteria. The results based on comments of Plasterer 1 were ranked according to eigen values and listed in Table 3.7. It can be noted that the commercial product has the ranking 5 while formulation 4 has the highest ranking. Similar matrices were obtained for the comments made by Plasterers

2, 3 and 4. Since the objective was to examine the effect of formulation, comparison was done only among the formulation listed in Table 3.2. These matrices are given in Appendix C. The final eigen values considering overall criteria were then obtained for the comments made by all the Plasterers and these values are summarized in Table 3.8.

Table 3.6– Comparison of each formulation for Ease of Mixing according to Plasterer 1

Formulation number	1	2	3	4	5	6	7	8	Eigen values
1	1/1	1/1	1/1	1/1	2/1	3/1	4/1	1/1	0.1670
2	1/1	1/1	1/1	1/1	2/1	3/1	4/1	1/1	0.1670
3	1/1	1/1	1/1	1/1	2/1	3/1	4/1	1/1	0.1670
4	1/1	1/1	1/1	1/1	2/1	3/1	4/1	1/1	0.1670
5	1/2	1/2	1/2	1/2	1/1	3/2	3/1	3/4	0.0926
6	1/3	1/3	1/3	1/3	2/3	1/1	2/1	1/2	0.0618
7	1/4	1/4	1/4	1/4	1/3	1/2	1/1	1/4	0.0379
8	1/1	1/1	1/1	1/1	4/3	1/2	4/1	1/1	0.1398

M3 =

	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8	Cr 9	Cr 10	Cr 11	Cr 12
Form 1	0.1670	0.0476	0.1538	0.0278	0.0393	0.1223	0.1333	0.1538	0.0258	0.1852	0.1724	0.1429
Form 2	0.1670	0.1429	0.0769	0.0833	0.1180	0.1223	0.1333	0.1538	0.0774	0.1481	0.1724	0.1429
Form 3	0.1670	0.1429	0.0385	0.1944	0.1418	0.1631	0.1333	0.1538	0.1745	0.1481	0.1379	0.1429
Form 4	0.1670	0.1429	0.1538	0.1111	0.1967	0.1631	0.1333	0.1538	0.1548	0.1481	0.1379	0.1429
Form 5	0.0926	0.1429	0.1538	0.2222	0.1418	0.1631	0.1333	0.1154	0.1290	0.1111	0.1034	0.1429
Form 6	0.0618	0.1429	0.1538	0.1389	0.1418	0.0816	0.1333	0.0769	0.2064	0.0741	0.0690	0.0952
Form 7	0.0379	0.1429	0.1154	0.0556	0.1418	0.0408	0.1333	0.0385	0.1806	0.0370	0.0345	0.0476
Form 8	0.1398	0.0952	0.1538	0.1667	0.0787	0.1437	0.0667	0.1538	0.0516	0.1481	0.1724	0.1429

	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8	Cr 9	Cr 10	Cr 11	Cr 12
Form 1	0.1670	0.0476	0.1538	0.0278	0.0393	0.1223	0.1333	0.1538	0.0258	0.1852	0.1724	0.1429
Form 2	0.1670	0.1429	0.0769	0.0833	0.1180	0.1223	0.1333	0.1538	0.0774	0.1481	0.1724	0.1429
Form 3	0.1670	0.1429	0.0385	0.1944	0.1418	0.1631	0.1333	0.1538	0.1745	0.1481	0.1379	0.1429
Form 4	0.1670	0.1429	0.1538	0.1111	0.1967	0.1631	0.1333	0.1538	0.1548	0.1481	0.1379	0.1429
Form 5	0.0926	0.1429	0.1538	0.2222	0.1418	0.1631	0.1333	0.1154	0.1290	0.1111	0.1034	0.1429
Form 6	0.0618	0.1429	0.1538	0.1389	0.1418	0.0816	0.1333	0.0769	0.2064	0.0741	0.0690	0.0952
Form 7	0.0379	0.1429	0.1154	0.0556	0.1418	0.0408	0.1333	0.0385	0.1806	0.0370	0.0345	0.0476
Form 8	0.1398	0.0952	0.1538	0.1667	0.0787	0.1437	0.0667	0.1538	0.0516	0.1481	0.1724	0.1429

×

0.1269	Cr 1
0.0501	Cr 2
0.0446	Cr 3
0.1053	Cr 4
0.1761	Cr 5
0.1411	Cr 6
0.0426	Cr 7
0.0667	Cr 8
0.0487	Cr 9
0.1152	Cr 10
0.0074	Cr 11
0.0754	Cr 12

$$e3 = \begin{pmatrix} 0.1081 \\ 0.1274 \\ 0.1518 \\ 0.1569 \\ 0.1411 \\ 0.1100 \\ 0.0788 \\ 0.1258 \end{pmatrix}$$

Table 3.7 – Ranking based on comments of Plasterer 1

Formulation number	Final eigen value	Rank
1	0.1081	7
2	0.1274	4
3	0.1518	2
4	0.1569	1
5	0.1411	3
6	0.1100	6
7	0.0788	8
8	0.1258	5

Table 3.8 – Final eigen values for overall criteria

Formulation Number	Plasterer 1	Plasterer 2	Plasterer 3	Plasterer 4
1	0.1081	0.0858	0.0908	0.1049
2	0.1274	0.0947	0.1071	0.1036
3	0.1518	0.1305	0.1641	0.1525
4	0.1569	0.1375	0.1743	0.1554
5	0.1411	0.1339	0.1446	0.1483
6	0.1100	0.1005	0.1323	0.1346
7	0.0788	0.0749	0.0942	0.1079

3.4 Results and Discussion

3.4.1 Categorization of industrial problem

The twelve problems listed in Table 3.1 can be divided into 2 main categories based on stage of operation namely preparation stage (paste mixing) and application stage (coating). The problems related to preparation stage are poor mixing, high air bubbles which can be seen after applying on the surface, agglomeration on mixing, poor flowability during mixing, unmixed lumps and insufficient water for mixing. They can be grouped into two main categories namely mixing difficulty and consistency difficulty. Rest of the problems are related to application stage and those can be divided into 3 categories as working difficulty, setting difficulty and trimming (sand papering) difficulty. This categorization is depicted in Table 3.9. The ranking of criterion obtained from AHP analysis is also given.

The results given in Table 3.9 indicate that the most important criterion for analyzing the quality of skim coat is ease of trimming. The other two criteria related to trimming difficulty namely sand paper marks and dust on trimming were given low ranking of 11 and 9 respectively. Therefore ease of trimming can be identified as the key criterion for analyzing the trimming difficulty. Similarly good workability, ease of mixing, optimum setting time and optimum water absorption by mixture can be identified as the key criteria for analyzing the working difficulty, mixing difficulty, setting difficulty and consistency difficulty respectively.

3.4.2 Analyzing the effect of thickener content

Ranking of criteria according to Plasterer 1 is given in matrix M3 in section 3.3.3. Similar matrices were obtained for other Plasterers and they are given in Appendix C. In M3, columns are representing the criteria and rows representing the formulation. Since formulation has been only changed by increasing the thickener content from 0.1 % to 0.7 %, variation of rank with the variation of thickener content for a given criterion can be obtained from the eigen values of respective column. Based on the categorization given in section 3.4.1, each type of difficulty was further analyzed. Key criterion for a given type of difficulty was selected for this analysis.

Table 3.9 – Categorization of problems

Stage	Type of difficulty	Problems behind the difficulties	Criterion	Rank
Preparation (paste mixing)	Mixing difficulty	Poor mixing	Ease of mixing	3
		Poor flowability during mixing	Good flowability during mixing	4
	Consistency difficulty	Bubbles after applying on the surface	Low air bubbles	10
		Agglomeration while mixing	Low agglomerates	7
		Unmixed lumps	Low unmixed lumps	12
		Stiff paste	Soft and uniform paste	6
Application (Coating)	Working difficulty	Dust during application	No dust surface	8
		Poor workability	Good Workability	2
	Setting difficulty	Fast setting	Long setting time	5
	Trimming difficulty	Difficult to trim	Ease of Trimming	1
		Sand paper marks	No sand paper marks	11
		Dust on trimming	Low trimming dust	9

3.4.2.1 Influence of cellulose ether on quality parameters of skim coat

Cellulose ethers are commonly introduced into cementitious materials such as mortars and skim coats, in order to obtain some of the required properties of the fresh paste and/or the hardened material [32]. Derivatives of cellulose ethers are macromolecules which improve the water retention and workability of the fresh material and also improve the adhesion to substrates [33]. They are designed to improve the workability of cementitious paste by controlling the water balance, i.e. water retention and suspension viscosity [34]. In other words CE balances the amounts of free water and retained water in the cementitious paste. However CE may also induce an uncontrolled and problematical retardation of cement hydration as a side effect [33,34].

Cellulose Ethers (CE) are insoluble in water because of the tight connection of the paired cellulose chains via hydrogen bridges. These bonds can be disrupted by partial or total etherification of the cellulose hydroxyl groups with various organic groups. Then the material becomes water soluble. Hydroxy Propyl Methyl Cellulose (HPMC), Hydroxy Ethyl Methyl Cellulose (HEMC) and Hydroxy Ethyl Cellulose (HEC) are examples for such derived water soluble materials [35]. In this research, HEC (as shown in Figure 2.2) based thickener was selected for analyzing the quality parameters of skim coat.

CE has a capability to form agglomerates when its content is high in the media and these agglomerates physically plug the pores of cementitious matrix in skim coat paste. This behavior had been reported for cellulose ethers in mortars [36, 37, 38]. When CE concentration is between 0.01 - 0.1%, the rheological behavior is Newtonian and when the concentration goes above 0.2%, rheology is changed as pseudoplastic or shear thinning. This changing concentration is known as overlap concentration. Above this overlap concentration, thickener agglomerates are formed, porosity is decreased and viscosity is increased. Further particle networks are also modified [38]. As a result of these effects, permeability is decreased and bleed water (free water) content is limited [39, 40]. Water permeability was also found to be influenced by the air entrainment. The entrained air may interrupt the otherwise continuous passages in which capillary flow of water takes place [41]. For cement mortars, controlling the matrix porosity was found to be important, since the matrix porosity is fundamental for water migration to the interfaces, shrinkage and cracking in the hardening mortar [42]. Similar effects can be expected with the skim coat also, due to the presence of about 12% white cement in formulations. In addition to the air entrainment and modifications to the particle networks above the overlapping concentration of CE, matrix porosity is highly influenced by the cement hydration process. Retardation of cement hydration was widely observed in the presence of macromolecular CE [43]. Since CE addition improves the water retention in fresh materials [36], further hydration is also possible if water is held in the hydrating medium for a longer time. CE also affects the carbonation kinetics and consequently the pore structure can be influenced [44].

3.4.2.2 Trimming difficulty

Ease of trimming was identified as the most important criterion for analyzing the quality of skim coat. Figure 3.1 shows the variation of eigen values for ease of trimming based on the comments of 4 Plasterers. The results suggest that presence of thickener is important in the formulation and trimming difficulty can be overcome by adding greater or equal to 0.3% of thickener.

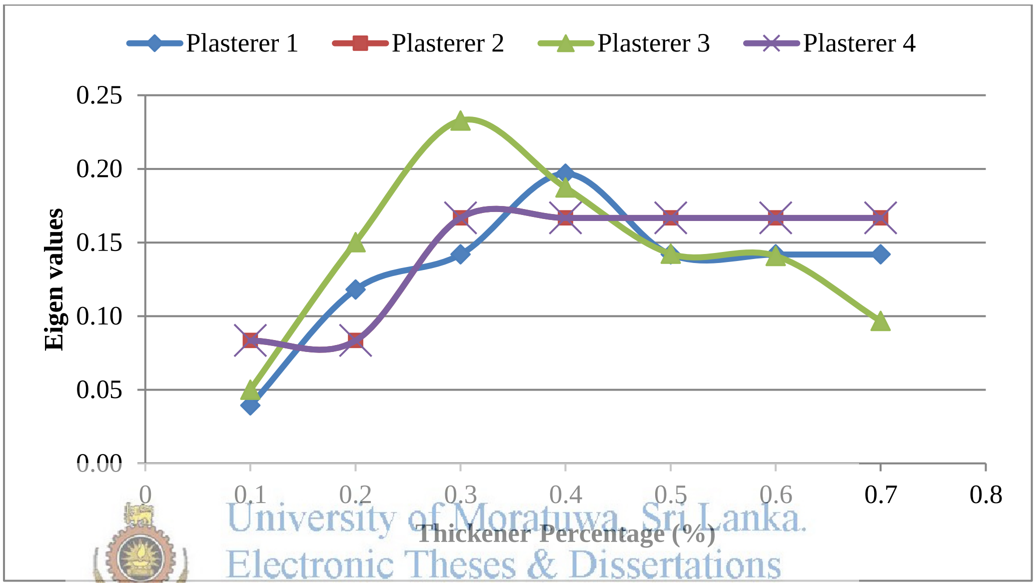

Figure 3.1– Variation of eigen values for Ease of Trimming

Trimming (Sand papering) is directly related with the surface finish of the coating. Rough and hard surfaces are difficulty to trim and give sand paper marks while soft surfaces give high trimming dust. The criterion "Ease of trimming" is mostly associated with the hardness and roughness of the surface. With the increase of CE, the retained water amount is increased while free water amount is decreased. As a result, cement hydration is delayed and coating is slowly dried. This will lead to soft and smooth surfaces which can be easily trimmed. On the other hand when free water amount is high, surface becomes rapidly dry due to evaporation [45] and the cement hydration may not be uniform. This will end up with hard and rough surfaces.

3.4.2.3 Working difficulty

Good workability was found to be an important criterion for analyzing the quality of skim coat with a ranking of 2. Further it was identified as the most important criterion for analyzing the working difficulty. Figure 3.2 depicts an optimum range of 0.3-0.6% of thickener in skim coat to have good workability in the fresh paste. Skim coat paste with good workability can be easily applied on the substrate using a trowel. Good workability means that paste is having good flowability and good adhesion to the substrate. When the thickener content was less than 0.3% the paste became more or less slurry. On the other hand, when thickener content was above 0.6% the paste became stiff.

Presence of free water is important to have good workability but too much of free water induces slurry nature to the paste. As the CE content in the paste is increased, workability improves due to decrease of free water amount and also due to increase of air entrainment. However when the CE content is increased above 0.6%, paste become stiff due to lack of free water in the paste resulting from high water retention and the increase of suspension viscosity. Due to the same reasons, mixing becomes difficult and a non-uniform paste is formed. This also contributes to the poor workability as observed with high CE content (>0.6%).

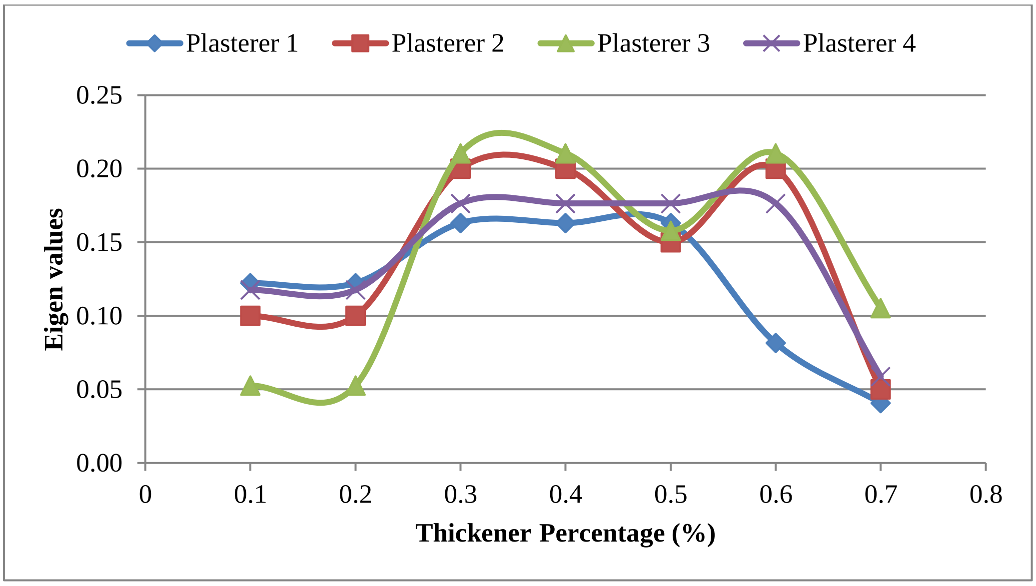

Figure 3.2– Variation of Eigen values for Good Workability

3.4.2.4 Mixing difficulty

Two types of problems are associated with mixing the paste namely poor mixing and poor flowability during mixing. Plasterers have identified both of them as important for analyzing the quality of skim coat with final ranking of 3 and 4 for the criteria "Ease of mixing" and "Good flowability during mixing". Considering the higher ranking, "Ease of mixing" was selected for further analysis and Figure 3.3 depicts the variation of eigen values with the increase of thickener content according to the comments of Plasterers.

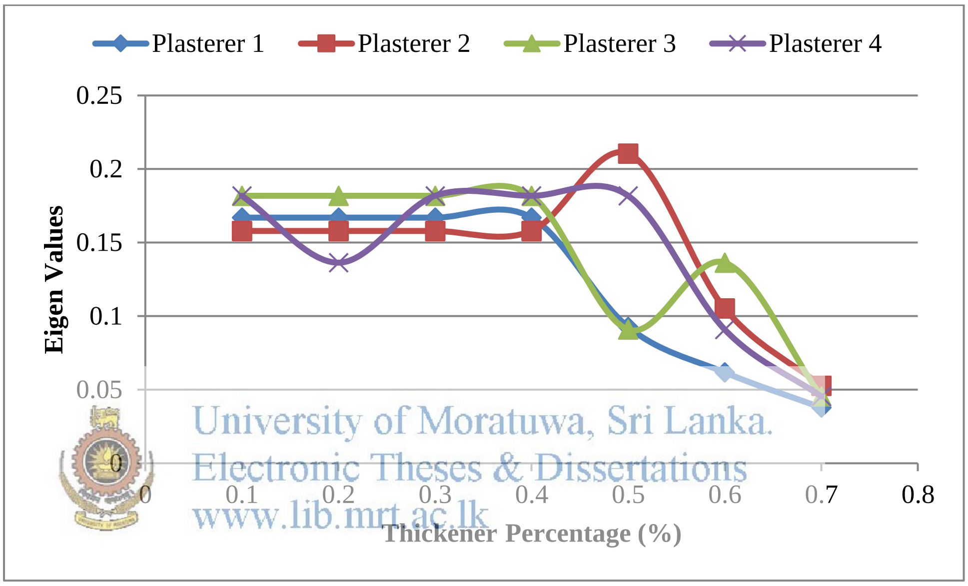

Figure 3.3 - Variation of Eigen values for Ease of mixing

In contrast to difficulty in trimming, high thickener content has a negative effect on ease of mixing. Plasterers found it easy to mix the formulations having thickener content of less than 0.5%. The influence of thickener on preparing the paste seems to be started with 0.5% as depicted in the Figure 3.4. Plasterer 2 and Plasterer 4 identified the formulation 5 as the best with regard to ease of mixing while Plasterer 1 and Plasterer 3 gave negative comments. This suggests that 0.5% is a critical amount of thickener with regard to ease of mixing. Above 0.5%, all the Plasterers found it difficult to mix.

Paste mixing is easy with the availability of sufficient amount of free water. Amount of free water decreases with the increase of CE content and the Plasterers found difficulty in mixing the paste with formulations having more than 0.4% thickener.

Therefore when the paste is becoming stiff, Plasterers identified it as poor mixing but the problem of becoming slurry was not highlighted when considering the ease of mixing.

3.4.2.5 Setting difficulty

There is only one criterion associated with the setting difficulty namely "Long setting time" which was assigned rank 5. According to Figure 3.4, setting time was improved with the increase of thickener content up to 0.3% and 0.3% to 0.5% can be identified as the optimum. Increasing the thickener content above 0.5% gave a negative effect.

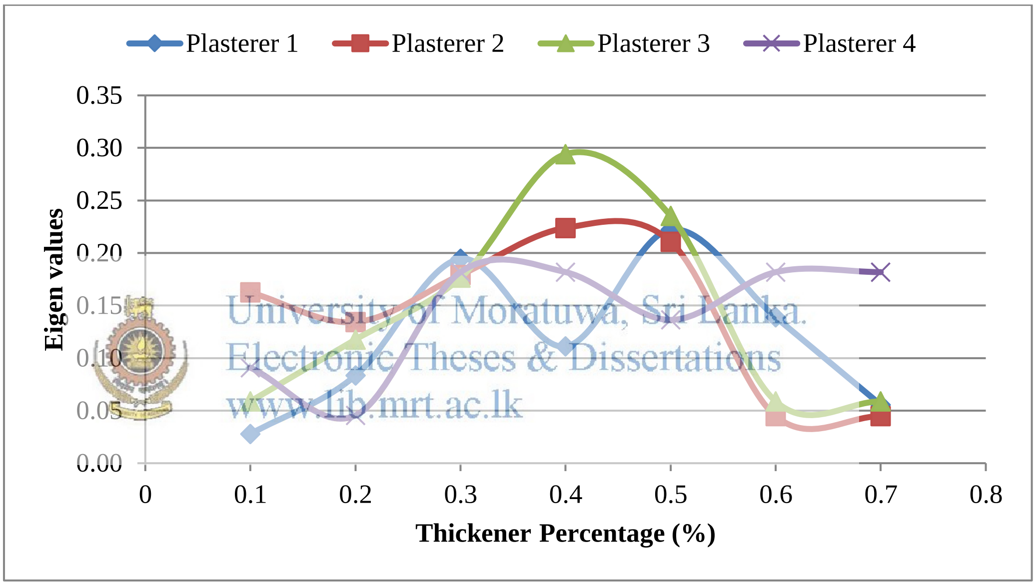

Figure 3.4– Variation of eigen values for Long Setting time

Setting time is the maximum time for the fresh paste to lose its workability. After preparation, paste becomes dry due to evaporation of free water [40]. This effect is more prominence with low thickener content as the retained water is low. Further, with high amount of free water cement hydration starts and that may also contribute to dry the paste. With the increase of thickener content, permeability of paste decreases and water is retained within the system. When the free water starts to evaporate, water balance is maintained by diffusing the retained water. This effect is depicted in Figure 3.4 as the optimum (0.3% to 0.5%) setting time. However, further increase of CE may significantly drop the permeability of the paste and considerably increase the suspension viscosity. Therefore water transport in the paste is affected and the setting time decreases as depicted in Figure 3.4 for thickener contents above 0.5%.

3.4.2.6 Consistency difficulty

Skim coat paste may become non uniform due to the presence of air bubbles, agglomerates, unmixed lumps and also become slurry or stiff paste. Based on the AHP analysis, the criterion of obtaining a soft and uniform paste was assigned the highest ranking among the other criteria associated with consistency difficulty. Figure 3.5 depicts that high thickener content has a negative effect on obtaining a soft and uniform paste.

When the free water amount is high, it is easy to mix the paste and to make a soft and uniform paste. Plasterers observed this as the availability of water without absorbing to the mixture. With the increase of CE content, water retention increases and observed as insufficient amount of water during mixing. This is depicted in Figure 3.5 as reduction of eigen values for formulations having thickener content above 0.6%.

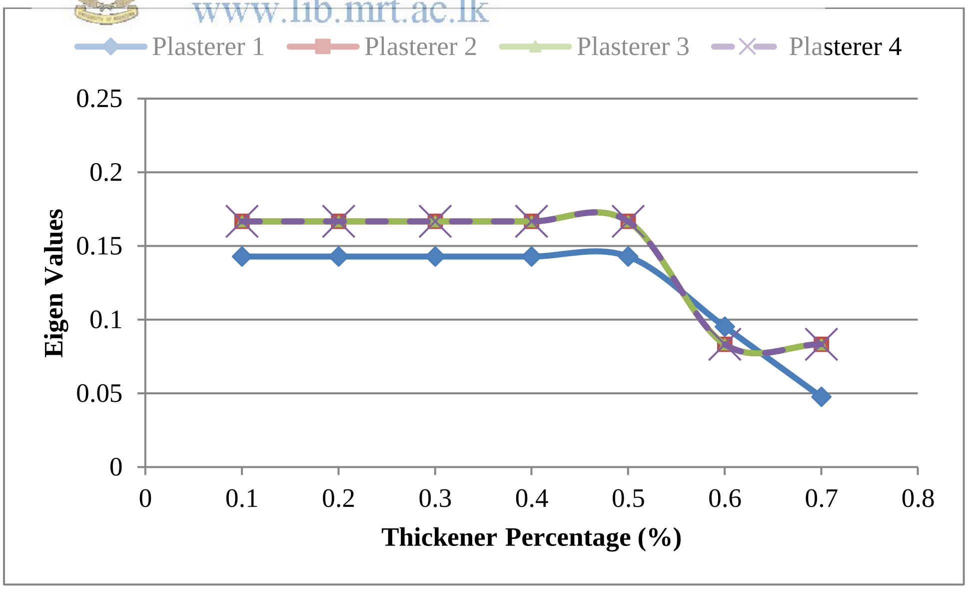

Figure 3.5 - Variation of Eigen values for Soft and Uniform paste

3.4.2.7 Overall analysis

Table 3.7 summarizes the overall ranking based on comments of Plasterer 1 for all the 12 criteria under investigation. Similar vectors were calculated for the comments made by three other Plasterers also. These results are given in Table 3.8 and shown in Figure 3.6. The overall results suggest that the optimum thickener content is in the range of 0.3-0.5% considering all the criteria. Too low or too high thickener contents have shown low eigen values as compared to other percentages.

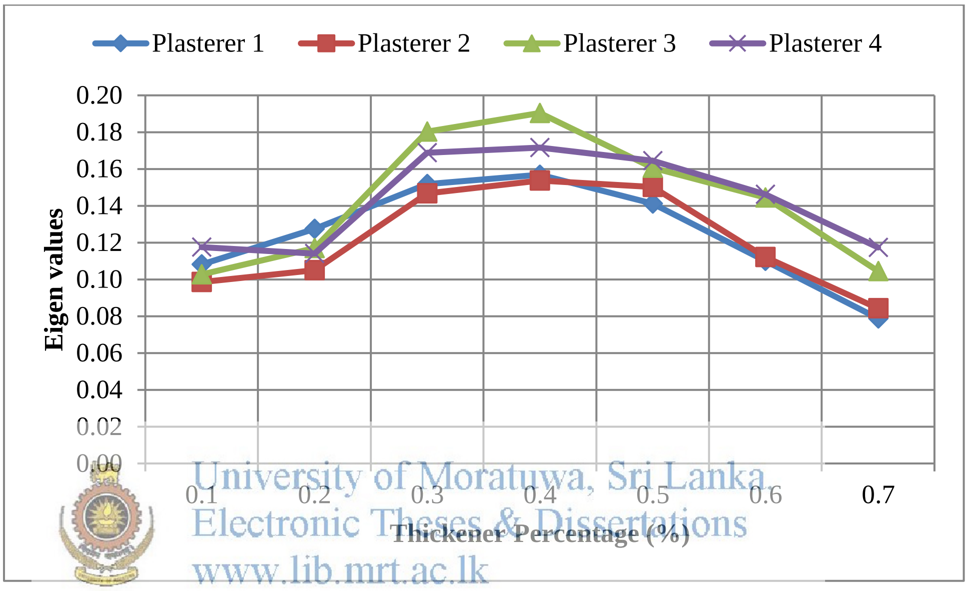

Figure 3.6– Final Eigen values based on the comments of 4 Plasterers

3.5 Conclusion

The results of Qualitative analysis solely depend on the feedback given by four different Plasterers. The problems have been evaluated in two stages as problems in sample preparation stage and problems in application stage. The favorable outcome of the mixing diffculty is ease of mixing. Mixing of paste was found to be easy with low thickener content of less than 0.5%. This may be mainly attributed to the availability of sufficient amount of free water in the paste. With the increase of thickener content (equal or above 0.5%), mixing was found to be difficult and the paste became stiff. Main function of a thickener is to retain water and to improve the workability. It also modifies the viscosity of the paste. The results of this study indicated an upper limit for the thickener content (0.5%) for preparing a soft and uniform paste without difficulty in mixing. On the other hand, results suggested a lower limit (0.3%) for trimming without difficulty. Cellulose ethers delay the cement hydration reaction by retaining water and hence the coating becomes soft and smooth. Workability and setting time are important properties of the fresh skim coat paste. These properties are highly dependent on the water balance in the paste which is influenced by the thickener content. With low amount of thickener, free water in the paste is too high and the paste becomes slurry and dries quickly. When thickener content is too high, the paste becomes stiff and loses the workability with low setting time. Therefore optimum thickener content for good workability and longer setting time was suggested in this study in the range of 0.3% – 0.5%. Also, according to the final eigen value plots, thickener content in the range of 0.3-0.5% gave the best output or problem free mixture considering all the 12 criteria, related to skim coat preparation and application.

4. QUANTITATIVE ANALYSIS OF THE INDUSTRIAL PROBLEM

4.1 Materials

The same materials reported in section 3.2, were used for experimental or quantitative analysis. The formulations given in Table 3.2 are valid for this section also.

4.2 Experiments and Testing Procedures

Cement is a main ingredient in skim coat with a content of about 12% and the physical behavior of skim coat paste is to a certain degree similar to cement paste. Therefore the two standard testing procedures used in analyzing cement paste namely flow table test and vicat needle depth test, were selected to examine the flowability and setting behavior of skim coat paste respectively. Flowability of skim coat can be related to working difficulty problem. If the flowability is good, then the mixture is assumed to be workable. Vicat needle depth test can be related with setting time of paste. With time the paste become hard and if the needle cannot be penetrated well through the paste, it is considered to be settled and vice versa. Both of these tests describe the rheology of the paste and hence they describe the viscosity and the variation of viscosity with time of skim coat paste.

Ram extrusion is a proven method for analyzing paste materials. Therefore Ram extrusion was also used to measure the flowability and setting time of skim coat. Pencil hardness test is commonly used to measure the surface hardness. Since the trimming difficulty is directly related to the surface hardness of the hardened and dried coating, pencil hardness test was used to analyze the trimming difficulty. Hard coatings are difficult to trim and surface scratches and marks appear on trimming. On the other hand if the coating is too soft, more matter is removed as dust.

4.2.1 Flow table test

A sample of skim coat paste (about 200 g) was mixed with water according to the correct ratio and the mixture was kept on the middle of the flow table with the aid of the standard mold as shown in Figure 4.1. It was flatted by using a trowel. Thereafter the mold was removed and 25 bumps were given to the paste by rotating the bottom wheel to raise the table up slowly and move down quickly. When bumping, paste was moved along the table radially outwards. At the end total flow distance was measured using a ruler. If the mixture is viscous, the distance is low and vice versa.

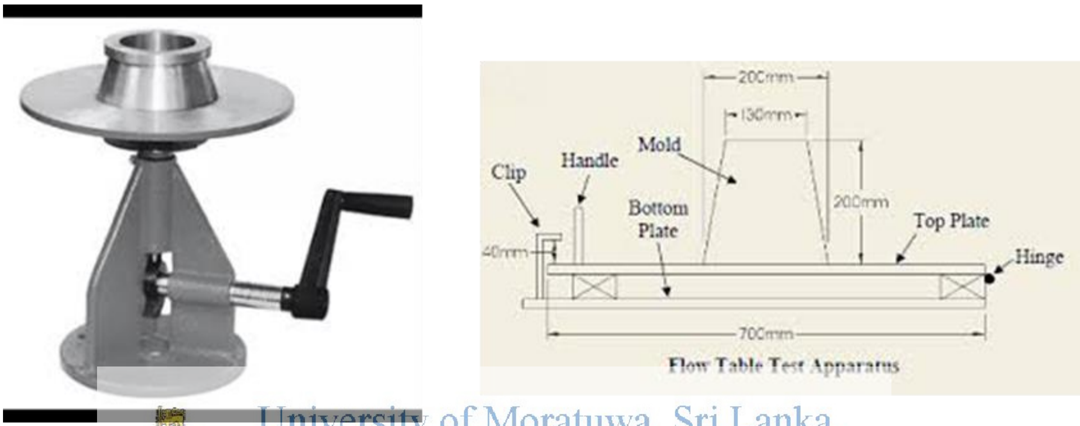

Figure 4.1 – Standard Flow Table appearance and dimensions

4.2.2 Vicat needle depth test

Sample of fresh skim coat paste (400 g) was poured into the standard mold up to the top mouth of the mold. The mold was having top and bottom diameter of 80 mm and 90 mm respectively and a height of 40 mm. Sample was flatted and the large needle (10 mm diameter) was connected as shown in Figure 2.6. The needle was moved slowly through the mixture. The scale reading was measured as the gap between the mold bottom plate and the needle end. Since the scale reading was observed to be 5 mm, the water content of paste (35%) was considered as correct.

Setting time was measured using the pin type needle of 1mm diameter. However, the needle touched the bottom of the mold even after 1 hour of setting. Therefore the large needle of 10 mm diameter was used in the analysis of setting time.

4.2.3 Ram Extrusion test

Ram extruder is a capillary type viscometer, widely used for measuring viscosity of paste materials. Since skim coat has to be prepared as a paste by adding water and properly mixing before applying as a wall plaster, ram extrusion was selected to measure the rheological behavior of fresh skim coat paste. A schematic diagram of ram extruder is shown in Figure 2.8. Paste material was filled into the bottom cylinder which has an orifice of 2.5 mm as shown in Figure 4.2. A freely movable plunger was used to force the paste through the orifice. A universal tensile testing machine with a load cell of 100 kN was used to provide the pressure to flow the material through the orifice. Figures 4.3 and 4.4 show the schematic diagrams of ram extruder and plunger.

The plunger was fixed into the end of load cell as a tensile jaw. All the experiments were performed with skim coat paste of samples 200 g containing 35% of water. The plunger was allowed to move at a constant speed of 100 mm/min and load cell data were recorded with time. After touching the sample surface a curve was plotted as compressive force against time (Abscissa is "time x 0.25" and Ordinate is Load). The graph obtained for formulation number 1 is shown in Figure 4.5. The peak load of this test was found to be 2800 kg. Similarly Peak load for each formulation was measured and the results are given in Figure 4.7.

Figure 4.2 – Ram Extruder connected to Universal Tensile Testing machine

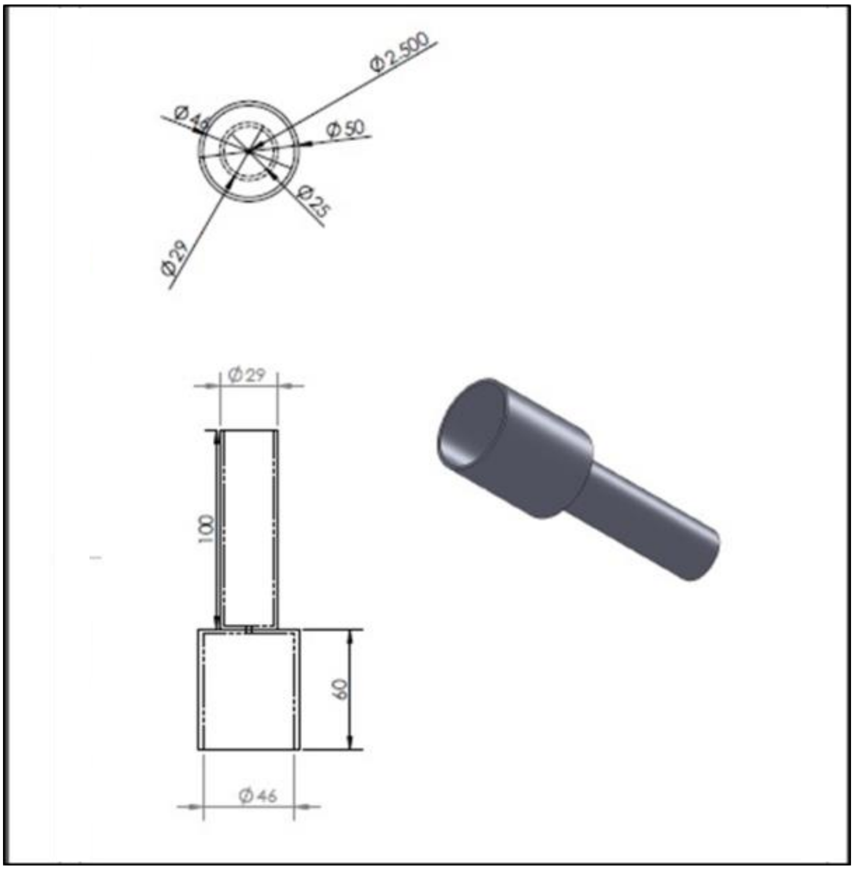

Figure 4.3 – Diagram of Ram extruder (All dimensions are in millimeters)

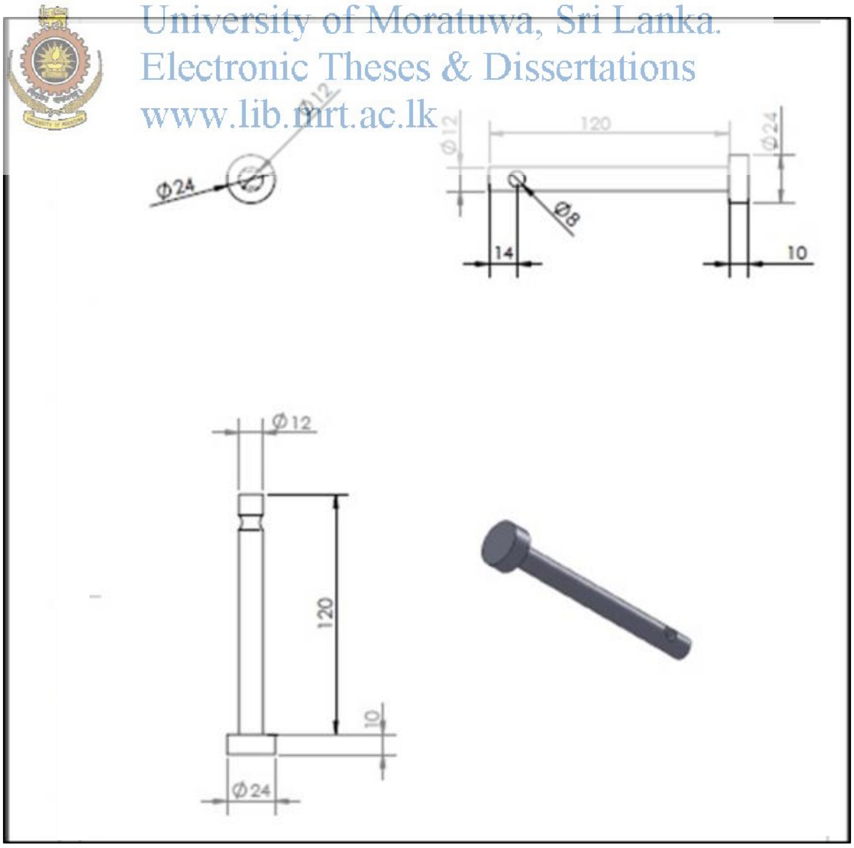

Figure 4.4 – Diagram of plunger (All dimensions are in millimeters)

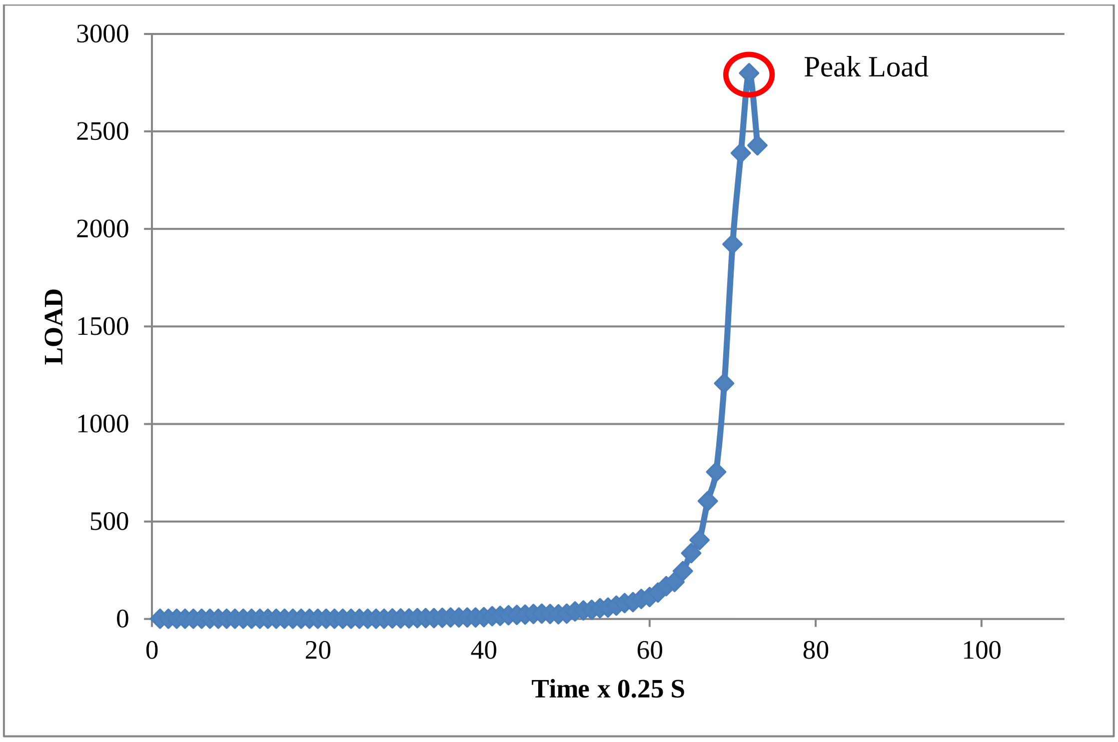

Figure 4.5 – Variation of extrusion load with time for formulation number 1

4.2.4 Define the setting time using Ram extrusion data

Fresh paste becomes hard with time and loses workability. Setting time can be defined as the maximum time duration before losing the workability and finding it difficult to apply. When the paste becomes hard it also loses the flowability and hence it will have higher peak load values in ram extrusion as compared to fresh paste. Therefore ram extrusion was used to analyze the setting time.

Fresh paste samples of 200 g each with 35% (w/w) of water were prepared for the formulations given in Table 3.2. They were allowed to dry naturally. Setting time of the skim coat paste was first assessed practically by visual observation of the dry surface and touching to see finger marks in 5 minutes intervals. After preparation and keeping as a lump, surface became gradually dry due to evaporation of water. On touch, surface gave finger marks easily before setting and it was difficult to place the finger marks after setting. The minimum time taken for the lump of skim coat to become dry and to give no finger marks on the surface was recorded as the setting time. The results of setting time for all the 7 formulations using similar technique are given in Table 4.1.

Table 4.1– Practically observed setting times for 7 basic formulations

Formulation Number	1	2	3	4	5	6	7
Setting time (min)	20	45	75	90	120	75	35

The maximum setting time of 120 minutes was observed for sample 5. Therefore formulation number 5 was selected as the reference sample for ram extrusion analysis. A sample weight of 1200g was prepared and divided into six lumps of 200 g each and five of them were allowed to dry naturally. One sample was used for ram extrusion as soon as the paste was prepared. Peak load variations at 30 minutes intervals were recorded from t=0 to t=150 minutes using these five samples. Figure 4.6 indicates the peak load variation with time for formulation 5 when allowed to dry naturally as described above.

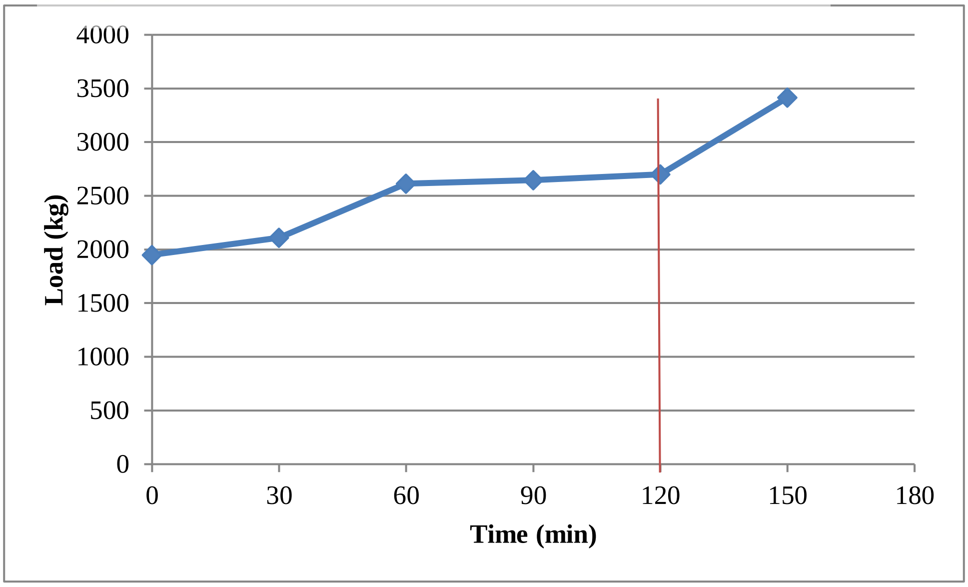

Figure 4.6– Peak load variation with time of setting for formulation 5

Results of practically observed setting time (Table 4.1) suggest that the setting time for formulation 5 is 120 minutes. Using this data and peak load variation shown in Figure 4.6, the corresponding peak load was found to be 2700 kg. Therefore peak load of 2700 kg was taken as the reference for analyzing the setting time of other formulations.

4.2.5 Set to touch drying time

Layer hardening time means the time taken to obtain a hardened dry layer after evaporating water. This is measured by set to touch drying time test. Industrially this test is done for paints. In this study, similar method was used for skim coat also. After applying a layer on a rough wall, stop watch was switched on and the stiffness was observed by finger touch. Initially when the layer was touched, it gave a finger mark. But this ability reduces with time due to loss of flowability as a result of evaporating water. With time, surface became stiff and it became hard at finger touch. The time at this point was recorded as the set to touch drying time.

4.2.6 Pencil Hardness test

Skim coat was applied on a ceiling board and the coating was allowed to dry. First pencil of the pencil hardness kit had a fine tip of 9B. It was used to measure very low hardness values. The pencil was gripped in the holder and moved over the already applied and dried skim coat surface. Dust was removed with the aid of a brush and the surface was observed to see whether there were scraped marks by pencil. The test was continued using pencils in the order of increasing hardness until a pencil mark was observed. Then the hardness was taken as the previous pencil number which did not give any scratching on the coating. For example, if 6B pencil gave scratches, then the hardness was 7B. Table 2.2 shows the order of pencils in a pencil hardness kit. There are 20 number of pencils in this kit. Pencil hardness test was done for all the formulations given in Table 3.2.

4.2.7 Measuring dust content on trimming

The same coatings used in pencil hardness test were smoothened with sand paper (P120) and the dust was collected and weighed.

4.3 Results and Discussion

4.3.1 Test results of Flow table

Flow table test results are given in Table 4.2. All the formulations were having water content of 35%. Except for the Formulation 1 and Formulation 2, no significant difference was observed among the different thickener percentages. Also the repeatability of the test was very poor. Summary and total results of ANOVA single factor test are given in Tables 4.3 and 4.4 respectively.

Table 4.2– Flow table test results

Formulation Number	1	2	3	4	5	6	7
Dolomite (%)	87.6	87.5	87.4	87.3	87.2	87.1	87.0
Cement (%)	12	12	12	12	12	12	12
Polymer (%)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Thickener (%)	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Average Flow table distance (cm)	15	14	12.2	12.8	12.3	12.3	12.8

Table 4.3 – Summary of ANOVA single factor test for flow table distance

Groups	Count	Sum	Average	Variance
1	3.0	45.0	15.0	1.0
2	3.0	42.0	14.0	1.0
3	3.0	36.5	12.2	1.6
4	3.0	38.5	12.8	1.1
5	3.0	37.0	12.3	2.3
6	3.0	37.0	12.3	1.6
7	3.0	38.5	12.8	1.1

Table 4.4 – ANOVA single factor results for flow table distance

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	19.81	6.00	3.30	2.39	0.08	2.85
Within Groups	19.33	14.00	1.38			
Total	39.14	20.00				

According to analysis of variance (Table 4.4), P value is 0.08 and it is greater than 0.05. Therefore the flow table distance values are not significant. Thus flow table test results are not reliable and cannot be used to quantitatively analyze the predicted difficulties associated with application of skim coat.

4.3.2 Results of Vicat needle depth test

Vicat needle depth measurement was taken at 10 minutes intervals up to 2 hours using the large needle to find the setting time of fresh skim coat paste. However, the variation of scale reading with time was found to be not statistically significant at 95% confidence interval ($p < 0.05$). Further, variation among different formulations was also found to be not statistically significant at 95% confidence interval ($p < 0.05$). Therefore use of Vicat needle depth test for analyzing the setting time of fresh skim coat paste was considered as not reliable.

4.3.3 Ram extrusion analysis

4.3.3.1 Peak load variation

Figure 4.5 shows the variation of ram extrusion force when the plunger moves downwards. The maximum point was taken as the peak load at which resistance to flow of paste through the die becomes the maximum. In other words, the shear stress of the paste in the barrel becomes the maximum. According to machine settings, tensometer was stopped immediately after attaining the peak load. Figure 4.7 shows the peak loads of 7 different formulations obtained for triplicated tests. The curve demonstrates the average of the peak loads obtained for corresponding formulations. According to the curve, formulation 3, 4 and 5 have the lowest peak load among other formulations. Lowest peak load means the lowest viscosity of the samples.

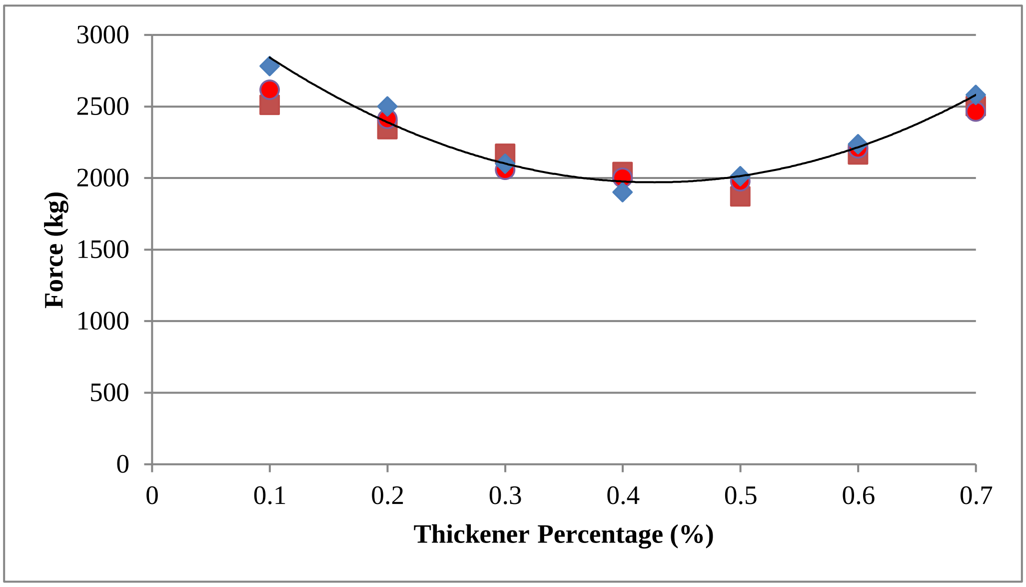

Figure 4.7– Extrusion Peak load variation with thickener percentage

Peak load has been reduced with the increase of thickener content up to 0.5% and then it has been increased with thickener content beyond 0.6%. Paste viscosity is a function of water balance in the fresh paste. When the thickener content is low, water retention in the paste is poor and the water is available as free water. Further the uniformity of the paste is low. During ram extrusion, this free water is removed due to seepage and the paste become stiff with the motion of the plunger. As a result the peak load increases. AS explained in the qualitative analysis (refer section 3.4.2.1), water retention in the paste improves with the increase of thickener content. Therefore water balance improves and the workability and the flowability of fresh paste improve. This can observed with the reduction of peak load of ram extrusion up to the thickener content of 0.5%. However, further increase in thickener content may result in low amount of free water which is not adequate to have a uniform paste. Further the water balance is greatly affected and both workability and the flowability are affected. This is indicated in Figure 4.7, where the peak load is significantly increased for formulations having thickener content above 0.5%.

4.3.3.2 Variation of setting time

As described in section 4.2, ram extrusion data were used to analyze the variation of setting time with the thickener amount. Formula 5 was selected as the reference sample and corresponding load of 2700 kg was selected as the reference loading at setting time. Table 4.5 summarizes the peak load values of all the 7 formulations at

30 minutes intervals. These data were interpolated to find the time corresponding to the load of 2700 kg which was taken as the setting time for a given formula. Further visual observations for dry surface and "touching to see finger mark" was also found as practical observations of setting time. Setting times observed from both Ram extrusion data and practical observations are summarized in Table 4.6 and Figure 4.8.

Table 4.5– Comparison of peak load variation with time

Time (min)	0	30	60	90	120	150
Formulation 1	2429	2739				
Formulation 2	2381	2477	2735	2737		
Formulation 3	2027	2348	2472	3328		
Formulation 4	2017	2044	2445	2749		
Formulation 5	1950	2110	2615	2645	2700	3415
Formulation 6	2156	2176	2373	2800		
Formulation 7	2445	2705	3146			

N/A –Not applicable

Table 4.6– Comparison of setting time based on Ram extrusion data and practical observation

Thickener Percentage (%)	Setting time (min)	
	Ram extrusion	Practical Observation
0.1	26	20
0.2	56	45
0.3	68	75
0.4	85	90
0.5	120	120
0.6	83	75
0.7	29	35

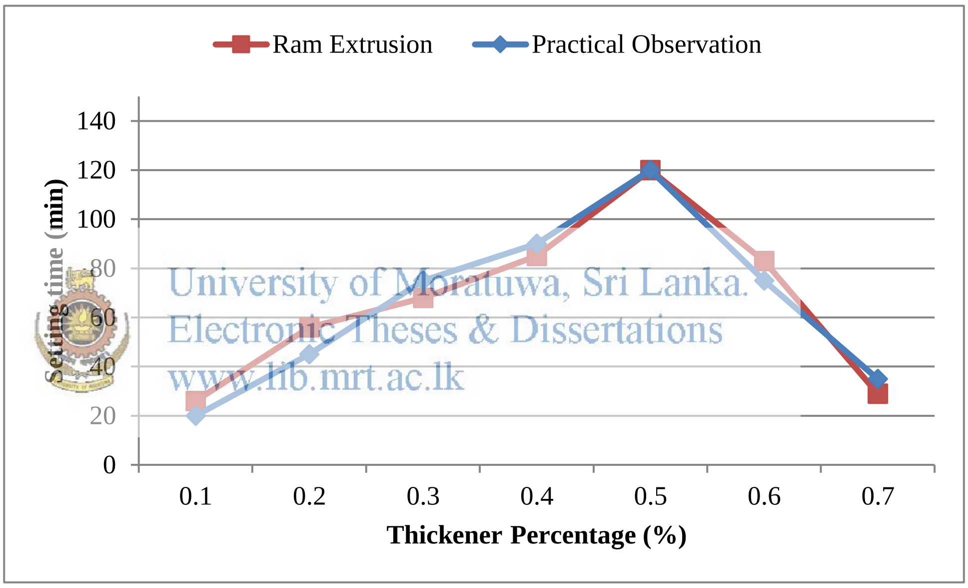

Figure 4.8–Setting time variation of skim coat based on ram extrusion and visual observation

Figure 4.6 indicates that setting time obtained from Ram extrusion data are very closely following the trend of practical observation. Hence it can be considered that Ram extrusion is a reliable method for analyzing the setting time of skim coat.

Thickener percentage in a formulation is important for water retention of skim coat which directly affects the setting time. Longer setting time is preferable at application stage as professional plasterers prefer to retain the workability of a fresh paste for a sufficient time. Usually according to industrial practice the preferable time to retain workability is about 90 minutes. Figure 4.8 indicates that formula 5 had the maximum setting time while formulation 4 and 6 had setting times close to 90 minutes. According to the experimental results (Figure 4.8) acceptable setting time can be observed in the thickener range of 0.3-0.6%. In fresh paste with low thickener concentrations, water retention is low and free water is high. Then cement hydration is fast and free water evaporates [40]. Due to both reasons mixture settles rapidly and setting time is low. When the thickener content is increased water retention improves and the free water content is reduced as explained in section 3.4.2. Then hydration reaction becomes slow and the available free water is also evaporates rather slowly. Thus setting time becomes comparatively high. However when the thickener content is further increased, free water content is limited and releasing of retained water is also restricted. As a result water balance in the fresh paste is greatly affected and workability becomes poor. This is observed as dry paste on visual observation and a significantly peak load in ram extrusion.

4.3.4 Set to touch drying time

Set to touch drying time explains how fast the coating becomes dry after application. If the drying time is too rapid, coating becomes weak and cracks can be formed due to rapid evaporation of water. On the other hand, if the drying time is too low, users have to wait for longer times before applying the second coating and also for trimming. Similar to setting time, set to touch drying time is also a direct function of the amount of thickener available in the formula. Tables 4.7 and 4.8 summarize the results of set to touch drying time with ANOVA test. Results (Column 4 of Table 4.7) indicate that set to touch drying time of formulations with thickener content less than or equal to 0.3% (Sub group 1) are significantly different to the formulations with greater than 0.3% (Sub group 2). Specifically the group 1 formulations had rapid drying (≤30 minutes) and hence the particles may loosely bonded and cracks can be formed in the coating, making it weak.

For set to touch drying time, a maximum value of about 60 minutes could be observed in the range of 0.4-0.5% of thickener. ANOVA test was done to check the significance of test results. P value is very close to zero. Therefore the results are highly acceptable. The variation of set to touch drying time was very similar to variation of setting time and a similar explanation is applicable as described in section 4.3.3.2.

Table 4.7 – Summary of ANOVA single factor test for Set to touch drying time

Groups	Count	Sum	Average	Variance
1 (Sub group 1)	3	65	21.67	8.33
2 (Sub group 1)	3	80	26.67	8.33
3 (Sub group 1)	3	95	31.67	8.33
4 (Sub group 2)	3	175	58.33	8.33
5 (Sub group 2)	3	165	55.00	25.00
6 (Sub group 2)	3	155	51.67	8.33
7 (Sub group 2)	3	140	46.67	8.33

Table 4.8 – ANOVA single factor results for Set to touch drying time

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3916.67	6.00	652.78	60.93	0.000000003132	2.85
Within Groups	150.00	14.00	10.71			
Total	4066.67	20.00				

4.3.5 Hardness test of skim coat

The results of pencil hardness test are given in Table 4.9. Hardness has increased with the increase of thickener percentage up to a maximum of 0.4%. Then a moderate hardness of 2B was achieved for 0.5% and 0.6% followed by a low hardness for 0.7%. This result also suggests achieving optimum properties in the range of 0.4-0.6%.

Table 4.9– Comparison of hardness for different formulations

Formulation Number	Pencil Hardness
1	9B
2	8B
3	3B
4	H
5	2B
6	2B
7	6B
Commercial	7B

According to these results, the maximum hardness is observed in formulation 4. It is the same sample which gave low dust content. Pencil hardness values of 3B and 2B for samples 3 and 5 respectively are acceptable. These samples gave low dust content during test. In hardness values and the dust content were found to be similar for formulation 5 and 6.

The hardness value is very low for formulations 1 and 2. This result confirms the previous observations of setting time and set to touch drying time. Hardness is a surface quality and directly linked to the drying of the coating. When the thickener content is low, coating is dried rapidly and cement hydration is not uniform. On the other hand if the thickener content is too high as in the case of formulation 7, again cement hydration is retarded due to poor water balance. As a result the coating is dried slowly and surface becomes soft.

4.3.6 Results of dust weight on trimming

Trimming is an essential requirement for skim coating as it gives the final finishing to the surface. If the coating is too hard, trimming will be difficult and surface becomes rough with scratch marks. On the other hand, if the surface is too soft, surface becomes smooth but not hard enough to withstand external forces. As a result of that, surface gets damaged easily. Weight of the dust collected in trimming is a good measurement of hardness of the surface. If the particles are loosely bound, the surface becomes soft and more dust is collected in trimming. Figure 4.9 shows the variation of dust weight with the thickener percentage.

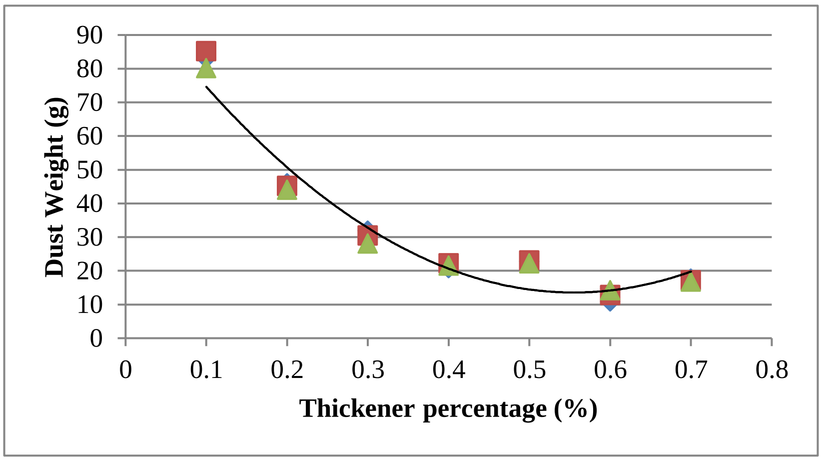

Figure 4.9– Variation of dust weight with thickener percentage

According to Figure 4.9, hardness of the surface increases with the increase of thickener percentage. These results indicate that thickener percentage in the range 0.3-0.6% gives a moderate hardness as compared to low hardness values of formulations having thickener concentration of less than 0.3%. Even though the hardness value for formulation 7 is low, the dust content low. This may be resulting from the very slow drying of the coating for formulation 7 and the formation of a soft surface.

4.4 Conclusion

Quantitative analysis was conducted with the purpose of identifying the possible test methods to evaluate the main industrial problems associated with powder type skim coat. Flow table test and Vicat need depth measurement which are considered as conventional methods of analyzing the cementitious pastes, were found to be not reliable for analyzing the skim coat pastes. Ram extrusion could be successfully used to analyze the workability and setting of fresh skim coat paste. Both workability and setting time of the fresh paste was found to have a direct relationship with the thickener content in the formulation. Results indicated optimum thickener content in the range of 0.3% to 0.6% which could be explained with reference to the water balance within the paste in the presence of cellulose thickener. Set to touch drying time and dust weight on trimming are related to surface properties of coating and hence to the drying behavior of coating. With low thickener content, surface became soft due to poor bonding between particles as a result of rapid drying. Good surface properties could be achieved with thickener content in the range of 0.3 – 0.6 %. When the thickener content was too high (i.e. above 0.6%), surface became soft again due to slow drying and retardation of cement hydration.

5. CONCLUSION

Problems associated with skim coat industry were identified by analyzing the comments of manufacturers, retailers and users (Professional plasterers). These problems were found to occur at 2 stages namely preparation (paste mixing) and application (coating). Two types of difficulties are faced during preparation and they are mixing difficulty and consistency difficulty. Application related difficulties are of 3 main types; working difficulty, setting difficulty and trimming difficulty. The problems are of 12 main types and AHP was used to analyze these problems according to their relative importance. The 12 problems when arranged according to the ranking given by the AHP analysis are difficult to trim, poor workability, poor mixing, poor flowability during mixing, fast setting, stiff paste, agglomeration while mixing, dust during application, dust on trimming, bubbles after applying on the surface, sand paper marks and unmixed lumps.

Further analysis on these problems based on the comments made by professional plasterers suggested upper and lower limits for thickener content. Mixing of paste was found to be easy and a consistent paste could be prepared with low thickener content of less than 0.5%. This may be mainly attributed to the availability of sufficient amount of free water in the paste. With the increase of thickener content (equal or above 0.5%), mixing was found to be difficult and the paste became stiff. Trimming was found to be easy for formulations having minimum thickener content of 0.3% or above. Optimum thickener content was found to be the range of 0.3% to 0.5% to achieve good workability and longer setting time.

Results of the quantitative analysis were in line with the results of qualitative analysis. Flow table test and Vicat needle depth measurement are conventionally used testing methods for analyzing the cementitious pastes. However, they were found to be not reliable for analyzing skim coat paste. Ram extrusion method was found to be a reliable method for analyzing workability and setting of fresh skim coat paste. Results of ram extrusion test suggested optimum thickener content of 0.3 – 0.5% for having good workability and the range of 0.3 – 0.6% for having longer setting time in fresh skim coat paste. Surface properties of the coating of skim coat paste after application on wall could be successfully tested with set to touch drying time, pencil hardness and weight of trimming dust. Set touch drying time clearly indicated that the rate of drying was reduced with the increase of thickener content up to 0.6 % due to improve in water retention and the control of water balance. However, further increase in thickener content affected the uniformity in mixing and the water balance in the paste as observed by the increase in drying rate. Fast drying may end up with hard surfaces with loosely bound particles. Optimum drying as in the case of formulation 5 with 0.5% thickener content gives smooth surfaces with strongly bound particles.

The results of overall analysis for 12 problems listed in qualitative analysis and the results of quantitative analysis are consistent and suggest optimum thickener content of 0.3 – 0.5% for skim coat formulations.

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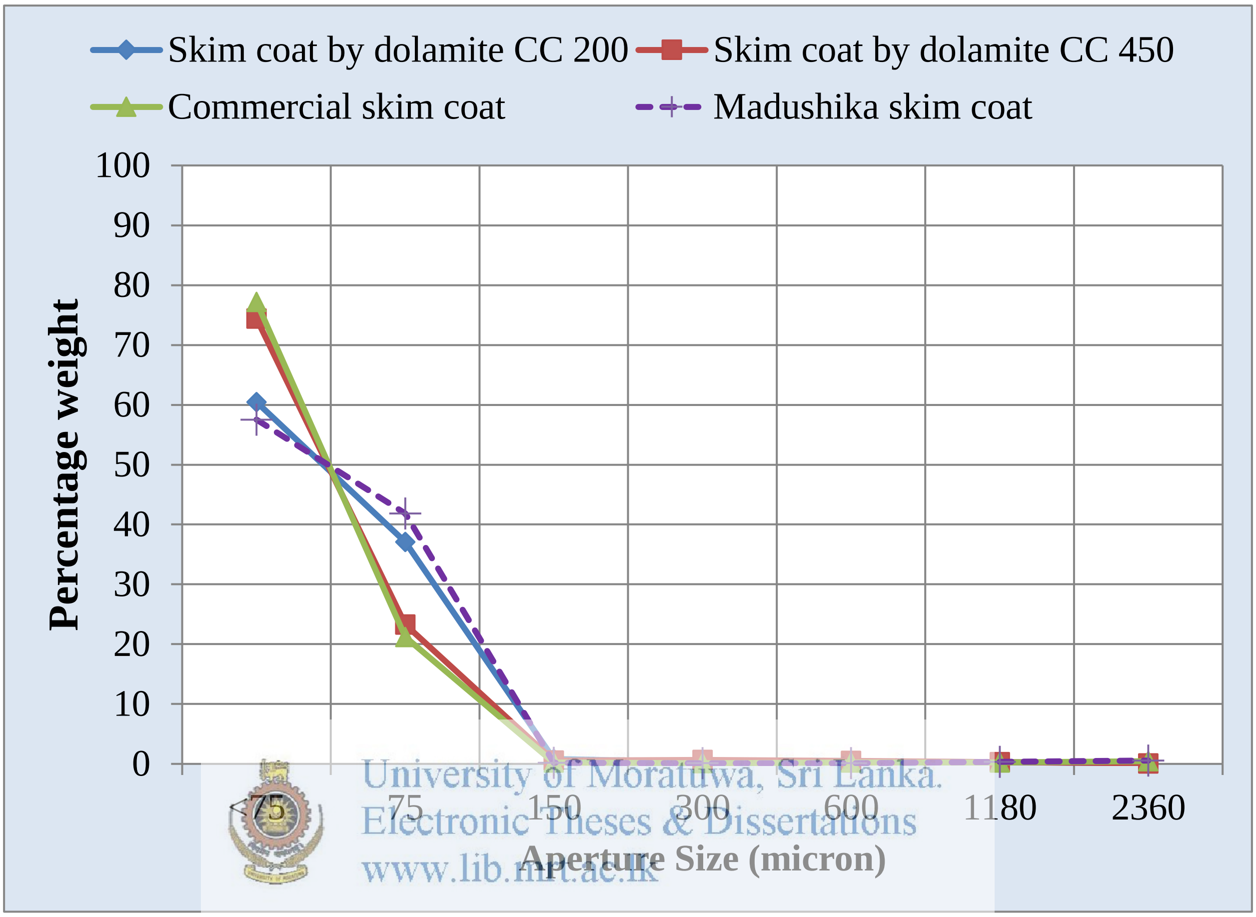
Appendix A – Particle size distribution of different skim coat types



Appendix B – Comparison between formulations for criteria based on the comments of Plasterer 1

Table B.1 – Comparison of each formulation for No dust surface

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	1/3	1/3	1/3	1/3	1/3	1/3	1/2	0.0476
2	3/1	1/1	1/1	1/1	1/1	1/1	1/1	3/2	0.1429
3	3/1	1/1	1/1	1/1	1/1	1/1	1/1	3/2	0.1429
4	3/1	1/1	1/1	1/1	1/1	1/1	1/1	3/2	0.1429
5	3/1	1/1	1/1	1/1	1/1	1/1	1/1	3/2	0.1429
6	3/1	1/1	1/1	1/1	1/1	1/1	1/1	3/2	0.1429
7	3/1	1/1	1/1	1/1	1/1	1/1	1/1	3/2	0.1429
8	2/1	2/3	2/3	2/3	2/3	2/3	2/3	1/1	0.0952

Table B.2 – Comparison of each formulation for Low air bubbles after applying

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	4/2	4/1	4/4	4/4	4/4	4/3	1/1	0.1538
2	1/2	1/1	2/1	1/2	1/2	1/2	2/3	1/2	0.0769
3	1/4	1/2	1/1	1/4	1/4	1/4	1/3	1/4	0.0385
4	1/1	2/1	4/1	1/1	1/1	1/1	4/3	1/1	0.1538
5	1/1	2/1	4/1	1/1	1/1	1/1	4/3	1/1	0.1538
6	1/1	2/1	4/1	1/1	1/1	1/1	4/3	1/1	0.1538
7	3/4	3/2	3/1	3/4	3/4	3/4	1/1	3/4	0.1154
8	1/1	2/1	4/1	1/1	1/1	1/1	4/3	1/1	0.1538

Table B.3 – Comparison of each formulation for Long setting time

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	1/3	1/7	1/4	1/8	1/5	1/2	1/6	0.0278
2	3/1	1/1	3/7	3/4	3/8	3/5	3/2	1/2	0.0833
3	7/1	7/3	1/1	7/4	7/8	7/5	7/2	7/6	0.1944
4	4/1	4/3	4/7	1/1	1/2	4/5	2/1	2/3	0.1111
5	8/1	8/3	8/7	2/1	1/1	8/5	4/1	4/3	0.2222
6	5/1	5/3	5/7	5/4	5/8	1/1	5/2	5/6	0.1389
7	2/1	2/3	2/7	1/2	1/4	2/5	1/1	1/3	0.0556
8	6/1	2/1	6/7	3/2	3/4	6/5	3/1	1/1	0.1667

Table B.4 – Comparison of each formulation for Ease of Trimming

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	1/3	1/4	1/5	1/4	1/4	1/4	1/2	0.0393
2	3/1	1/1	3/4	3/5	3/4	3/4	3/4	3/2	0.1180
3	4/1	4/3	1/1	4/5	1/1	1/1	1/1	1/2	0.1418
4	5/1	5/3	5/4	1/1	5/4	5/4	5/4	5/2	0.1967
5	4/1	4/3	1/1	4/5	1/1	1/1	1/1	1/2	0.1418
6	4/1	4/3	1/1	4/5	1/1	1/1	1/1	1/2	0.1418
7	4/1	4/3	1/1	4/5	1/1	1/1	1/1	1/2	0.1418
8	2/1	2/3	1/2	2/5	1/2	1/2	1/2	1/1	0.0787

Table B.5 – Comparison of each formulation for Good workability

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	1/1	3/4	3/4	3/4	3/2	3/1	3/4	0.1223
2	1/1	1/1	3/4	3/4	3/4	3/2	3/1	3/4	0.1223
3	4/3	4/3	1/1	1/1	1/1	2/1	4/1	1/1	0.1631
4	4/3	4/3	1/1	1/1	1/1	2/1	4/1	1/1	0.1631
5	4/3	4/3	1/1	1/1	1/1	2/1	4/1	1/1	0.1631
6	2/3	2/3	1/2	1/2	1/2	1/1	2/1	1/2	0.0816
7	1/3	1/3	1/4	1/4	1/4	1/2	1/1	1/4	0.0408
8	4/3	4/3	1/1	1/1	1/1	2/1	1/4	1/1	0.1437

Table B.6 – Comparison of each formulation for No sand paper marks

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	2/1	0.1333
2	1/1	1/1	1/1	1/1	1/1	1/1	1/1	2/1	0.1333
3	1/1	1/1	1/1	1/1	1/1	1/1	1/1	2/1	0.1333
4	1/1	1/1	1/1	1/1	1/1	1/1	1/1	2/1	0.1333
5	1/1	1/1	1/1	1/1	1/1	1/1	1/1	2/1	0.1333
6	1/1	1/1	1/1	1/1	1/1	1/1	1/1	2/1	0.1333
7	1/1	1/1	1/1	1/1	1/1	1/1	1/1	2/1	0.1333
8	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/1	0.0667

Table B.7 – Comparison of each formulation for Low agglomerates

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	1/1	1/1	1/1	4/3	2/1	4/1	1/1	0.1538
2	1/1	1/1	1/1	1/1	4/3	2/1	4/1	1/1	0.1538
3	1/1	1/1	1/1	1/1	4/3	2/1	4/1	1/1	0.1538
4	1/1	1/1	1/1	1/1	4/3	2/1	4/1	1/1	0.1538
5	3/4	3/4	3/4	3/4	1/1	3/2	3/1	3/4	0.1154
6	1/2	1/2	1/2	1/2	2/3	1/1	2/1	1/2	0.0769
7	1/4	1/4	1/4	1/4	1/3	1/2	1/1	1/4	0.0385
8	1/1	1/1	1/1	1/1	4/3	2/1	4/1	1/1	0.1538

Table B.8 – Comparison of each formulation for Low trimming dust

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	1/3	1/4	1/6	1/5	1/8	1/7	1/2	0.0258
2	3/1	1/1	3/4	3/6	3/5	3/8	3/7	3/2	0.0774
3	4/1	4/3	1/1	2/3	4/5	1/2	4/1	2/1	0.1745
4	6/1	2/1	3/2	1/1	6/5	3/4	6/7	3/1	0.1548
5	5/1	5/3	5/4	5/6	1/1	5/8	5/7	5/2	0.1290
6	8/1	8/3	2/1	4/3	8/5	1/1	8/7	4/1	0.2064
7	7/1	7/3	7/4	7/6	7/5	7/8	1/1	7/2	0.1806
8	2/1	2/3	1/2	1/3	2/5	1/4	2/7	1/1	0.0516

Table B.9 – Comparison of each formulation for Good flowability during mixing

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	5/4	5/4	5/4	5/3	5/2	5/1	5/4	0.1852
2	4/5	1/1	1/1	1/1	4/3	2/1	4/1	1/1	0.1481
3	4/5	1/1	1/1	1/1	4/3	2/1	4/1	1/1	0.1481
4	4/5	1/1	1/1	1/1	4/3	2/1	4/1	1/1	0.1481
5	3/5	3/4	3/4	3/4	1/1	3/2	3/1	3/4	0.1111
6	2/5	1/2	1/2	1/2	2/3	1/1	2/1	1/2	0.0741
7	1/5	1/4	1/4	1/4	1/3	1/2	1/1	1/4	0.0370
8	4/5	1/1	1/1	1/1	4/3	2/1	4/1	1/1	0.1481

Table B.10 – Comparison of each formulation for Low unmixed dry lumps

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	1/1	5/4	5/4	5/3	5/2	5/1	1/1	0.1724
2	1/1	1/1	5/4	5/4	5/3	5/2	5/1	1/1	0.1724
3	4/5	4/5	1/1	1/1	4/3	2/1	4/1	4/5	0.1379
4	4/5	4/5	1/1	1/1	4/3	2/1	4/1	4/5	0.1379
5	3/5	3/5	3/4	3/4	1/1	3/2	3/1	3/5	0.1034
6	2/5	2/5	1/2	1/2	2/3	1/1	2/1	2/5	0.0690
7	1/5	1/5	1/4	1/4	1/3	1/2	1/1	1/5	0.0345
8	1/1	1/1	5/4	5/4	5/3	5/2	5/1	1/1	0.1724

Table B.11 – Comparison of each formulation for Soft and uniform paste

Formulation number	1	2	3	4	5	6	7	8	Eigen Values
1	1/1	1/1	1/1	1/1	1/1	3/2	3/1	1/1	0.1429
2	1/1	1/1	1/1	1/1	1/1	3/2	3/1	1/1	0.1429
3	1/1	1/1	1/1	1/1	1/1	3/2	3/1	1/1	0.1429
4	1/1	1/1	1/1	1/1	1/1	3/2	3/1	1/1	0.1429
5	1/1	1/1	1/1	1/1	1/1	3/2	3/1	1/1	0.1429
6	2/3	2/3	2/3	2/3	2/3	1/1	2/1	2/3	0.0952
7	1/3	1/3	1/3	1/3	1/3	1/2	1/1	1/3	0.0476
8	1/1	1/1	1/1	1/1	1/1	3/2	3/1	1/1	0.1429

Appendix C – M3 matrices for the comments of Plasterers 2,3 and 4

Plasterer 2

Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8	Cr 9	Cr 10	Cr 11	Cr 12
0.1579	0.0000	0.1818	0.1625	0.0833	0.1000	0.0000	0.0000	0.1111	0.0556	0.0000	0.0000
0.1579	0.0000	0.1818	0.1343	0.0833	0.1000	0.0000	0.0000	0.2222	0.1111	0.0000	0.0000
0.1579	0.0000	0.0909	0.1791	0.1667	0.2000	0.0000	0.0000	0.2222	0.1667	0.0000	0.0000
0.1579	0.0000	0.1818	0.2239	0.1667	0.2000	0.0000	0.0000	0.1852	0.1667	0.0000	0.0000
0.2105	0.0000	0.1818	0.2107	0.1667	0.1500	0.0000	0.0000	0.1481	0.1667	0.0000	0.0000
0.1053	0.0000	0.0455	0.0448	0.1667	0.2000	0.0000	0.0000	0.0741	0.1667	0.0000	0.0000
0.0526	0.0000	0.1364	0.0448	0.1667	0.0500	0.0000	0.0000	0.0370	0.1667	0.0000	0.0000

Plasterer 3

Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8	Cr 9	Cr 10	Cr 11	Cr 12
0.1818	0.0000	0.1429	0.0588	0.0833	0.0526	0.0000	0.1669	0.0500	0.0455	0.2265	0.1667
0.1818	0.0000	0.1429	0.1176	0.0833	0.0526	0.0000	0.1669	0.1501	0.0909	0.2265	0.1667
0.1818	0.0000	0.1429	0.1765	0.1667	0.2105	0.0000	0.1669	0.2328	0.1818	0.1466	0.1667
0.1818	0.0000	0.1429	0.2941	0.1667	0.2105	0.0000	0.1669	0.1873	0.1818	0.1466	0.1667
0.0909	0.0000	0.1429	0.2353	0.1667	0.1579	0.0000	0.1353	0.1423	0.1818	0.1133	0.1667
0.1364	0.0000	0.1429	0.0588	0.1667	0.2105	0.0000	0.1294	0.1409	0.1818	0.0838	0.0833
0.0455	0.0000	0.1429	0.0588	0.1667	0.1053	0.0000	0.0676	0.0966	0.1364	0.0566	0.0833

Plasterer 4

Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8	Cr 9	Cr 10	Cr 11	Cr 12
0.1818	0.0000	0.1429	0.0909	0.0833	0.1176	0.0000	0.1669	0.0588	0.0556	0.2265	0.1667
0.1364	0.0000	0.1429	0.0455	0.0833	0.1176	0.0000	0.1669	0.1176	0.1111	0.2265	0.1667
0.1818	0.0000	0.1429	0.1818	0.1667	0.1765	0.0000	0.1669	0.1176	0.1667	0.1466	0.1667
0.1818	0.0000	0.1429	0.1818	0.1667	0.1765	0.0000	0.1669	0.1765	0.1667	0.1466	0.1667
0.1818	0.0000	0.1429	0.1364	0.1667	0.1765	0.0000	0.1353	0.1765	0.1667	0.1133	0.1667
0.0909	0.0000	0.1429	0.1818	0.1667	0.1765	0.0000	0.1294	0.1765	0.1667	0.0838	0.0833
0.0455	0.0000	0.1429	0.1818	0.1667	0.0588	0.0000	0.0676	0.1765	0.1667	0.0566	0.0833

Appendix D – Interpolations to find the time corresponding to 2700 kg

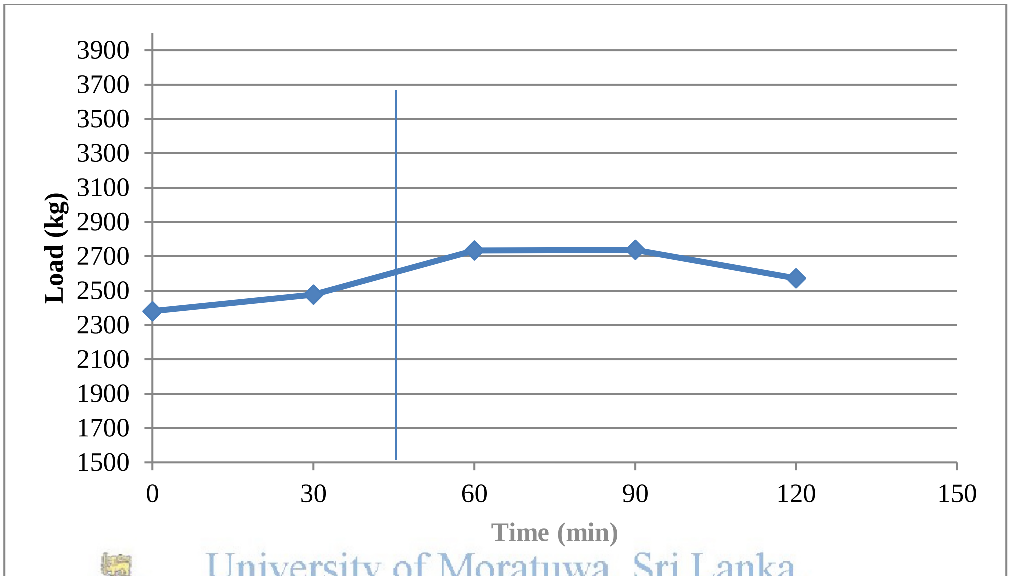


Figure D.1 – Peak load measurements of extrusion test for formulation 2 with time

Table D.1 – Interpolation to find the time at 2700 kg for formulation 2

30	2477
T=56	2700
60	2735

As applied for sample 1, time was calculated as 56 minutes.

Then for other samples also, above interpolation was done and obtained the setting time for formulation 3,4,6 and 7 as shown in the corresponding table